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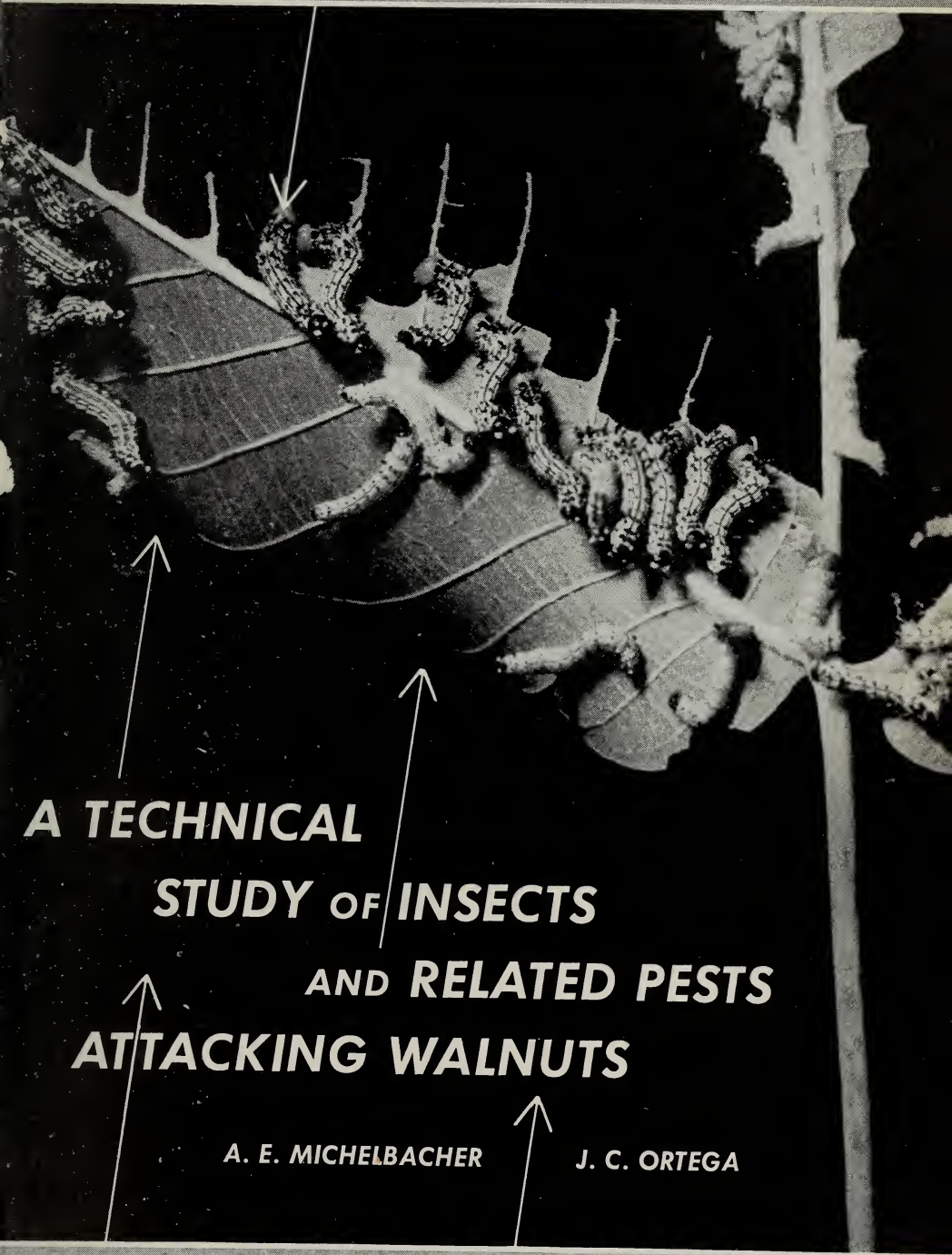

A TECHNICAL STUDY OF INSECTS AND RELATED PESTS ATTACKING WALNUTS

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CONTENTS

Page

I Lepidoptera 4
Codling moth 4
Filbertworm 20
Navel orangeworm 24
Red-humped caterpillar 28
Fruit tree leaf roller 32
Fall webworm 34
Walnut spanworm 34

II Homoptera (aphids) 35
Walnut aphid 35
Dusky-veined walnut aphid 44

III Homoptera (scale insects) 46
Unarmored scales 46
Frosted scale 46
European fruit lecanium 52
Calico scale 53
Other species of soft scales 55

Armored scales 55
Oystershell scale 55
Italian pear scale 56
Putnam scale 57
Walnut scale 58
Other species armored scales 58

The most important pests of English or Persian walnut are considered in this bulletin. It is designed to aid in the identification of the several insects and related pests that attack the crop. Information on life history, habits, damage, and the seasonal population trends is given. Control is limited primarily to those aspects that have to do with cultural measures and natural factors. Little is given on the use of insecticides because recommendations concerning their application are continually changing. For the latest information on pesticides, rates and methods of application, and other control measures, see your local University of California Farm Advisor.

Page

IV Wood borers (Coleoptera) 58
Pacific flatheaded borer 58
Dicerca horni Crotch 60
Spotted tree borer 60
Nautical borer 61
California prionus 61
Leptidiella brevipennis (Mulsant) 62
Monarthrum dentiger (Lec.) 62

V False chinch bug 62

VI Walnut husk fly 62

VII Spider mites 70
European red spider mite 70
Citrus red mite 71
Pacific spider mite 71
Two-spotted spider mite 72
Walnut blister mite 73
False spider mite 74

VIII Scavenger species 77

IX Insects attacking walnuts in storage 78
Indian-meal moth 78
Mediterranean flour moth 79
Saw-toothed grain beetle 79

Acknowledgments 81

Literature cited 82

A Technical Study of Insects and Related Pests Attacking Walnuts[1]

A. E. MICHELBACHER JOHN C. ORTEGA

I LEPIDOPTERA

CODLING MOTH

The codling moth, *Carpocapsa pomonella* Linn., is one of the most serious pests attacking walnuts. In California it was first observed near Concord in 1909, where an infestation was encountered by Foster (1912).[2] He conducted an extensive survey which disclosed a light but general infestation occurring throughout the central portion of Contra Costa County, with the intensity ranging from 5 to 50 per cent where walnut trees were adjacent to pear packing sheds, heavily infested pear orchards, or drying yards. The first definite record for southern California was 1913, as reported by Quayle (1926). In that year infestations of less than 1 per cent of the walnuts were found in Orange and Santa Barbara counties. However, infestations in the south reached such serious proportions by 1918 that investigations of the pest were undertaken by the California Agricultural Experiment Station. These studies have been continued, with varying emphasis, to the present time.

[1] Submitted for publication March 18, 1957.

[2] See "Literature Cited" for citations referred to in the text by author and date.

DESCRIPTION

The codling moth has four stages in its development: adult, egg, larva or caterpillar, and pupa.

Adult. The adult (fig. 1) at rest is about ½ inch long and has a wing expanse of approximately ¾ inch. Its brownish-gray color blends into the bark background when it is at rest on the tree.

Fig. 1. Codling moth adults. (Top × 1¾; bottom × 2¾)

The most distinguishing characteristic of the adult or moth is the coppery spot on the inner margin at the tip of each of the forewings.

Eggs. The adult female lays upward to 100 eggs. The eggs are laid singly, are oval, flattened, somewhat scale-like, and are slightly smaller than the head of an ordinary pin. At first the eggs are waxy white, but as the incubation period advances they darken with development of the embryo.

Larva or Caterpillar. The body of a newly hatched larva is whitish, with the head and prothoracic shield nearly black. In completing its development the larva casts its skin several times. On reaching maturity the body usually takes on a pinkish tinge. The pinkish color tends to disappear in the overwintering individual, so that by the following spring it is waxy white with a slight tendency toward pink. The head and prothoracic shield and the anal plate are amber. The dark markings on the head and the pinkish color of the body help to distinguish the larva of the codling moth from that of other species attacking walnuts. A mature larva is about $\frac{5}{8}$ inch long and is sparsely covered with rather long hairs. Upon reaching maturity the larva crawls under the bark of a tree or into any secluded place to pupate.

Pupa. Before the codling moth pupates, it spins a silken cocoon (fig. 2) and constructs a silken tunnel to the outside (fig. 3) to facilitate the emergence of the adult. When these preparations are completed, the larva pupates (fig. 3). The pupa is light amber at first, but it darkens as it transforms to the adult stage. At the time the moth is ready to emerge, the pupa frequently moves through the emergence tunnel and comes to rest protruding from it. Empty pupal cases are often seen projecting from the bark of trees or other locations where pupation has taken place.

Fig. 2. Bark removed from walnut tree showing an overwintering codling moth larva. (× 2)

SEASONAL LIFE HISTORY

There are at least two broods of codling moths each year. The trend of the adult moth flight as determined by bait pan catches at Linden, California, for the years 1943 to 1945 inclusive is shown in figure 4. Evidently there are two principal flight periods—one in the spring by the first brood, the other in the summer by the second brood.

Fig. 3. Bark removed from walnut tree showing codling moth pupae. (× 2)

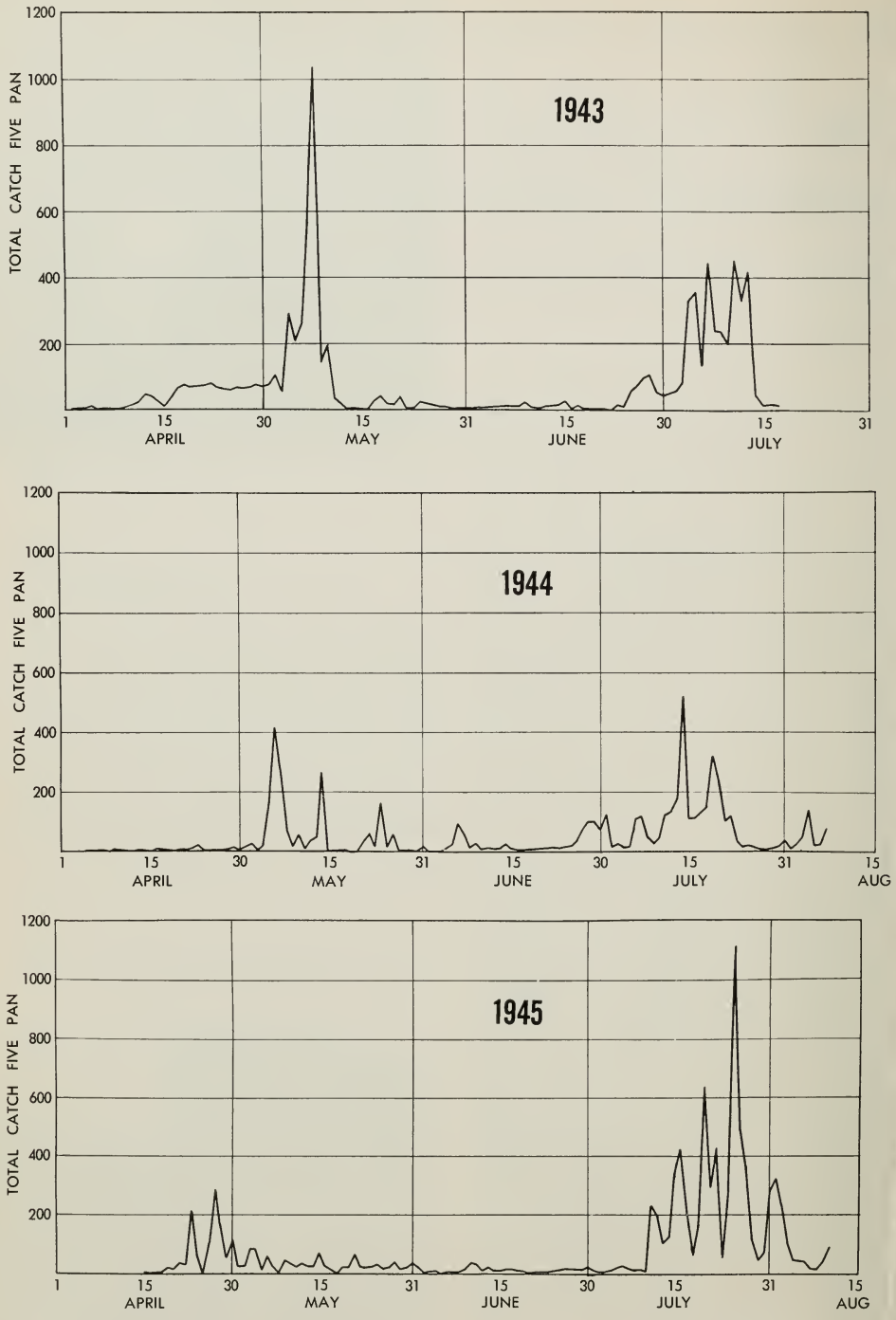


Fig. 4. Codling moth bait pan records at Linden for 1943 to 1945, inclusive.

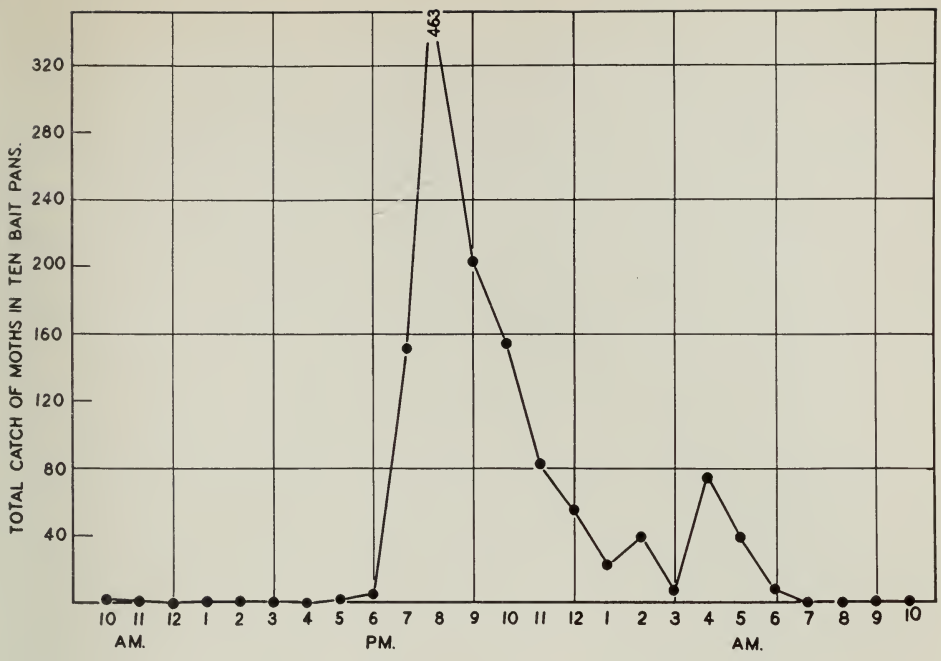


Fig. 4A. Codling moth hourly flight for a 24-hour period, 10 a.m. to 10 a.m., August 9 and 10, 1935.

Moth activity is most pronounced on warm days and during periods of low light intensity. In fact, most flight occurs during the night. In 1935, on August 9 and 10, hourly moth flight was determined for a 24-hour period by counting the number of moths trapped in 10 bait pans. Over the 24-hour period 1,280 moths were captured. The hourly distribution of the catch is graphically shown in figure 4A. Practically all the flight occurred during the night, and by far the greatest activity was in the early evening.

First Brood. The winter is spent as mature larvae in silken cocoons under the bark of trees or in any other secluded place, including packing sheds, other buildings, boxes and similar spots, or even in the soil. In late March the larvae begin to pupate and the first moths make their appearance during April. The largest number of moths of the first brood appear during the latter part of April to about the middle of May, although a scattering of individuals may continue through June or even later. It is interesting to note that Yothers and Carlson (1941) observed that some hibernating larvae may not emerge until the second season. The peak of emergence varies with different localities and with different seasons. It is usually earliest in the warmer interior valleys and latest in the cooler, coastal regions. Moth activity is most pronounced on warm days and during periods of low light intensity. Newly emerged moths mate and deposit eggs on the foliage and adjacent twigs, and later on the maturing nuts. The incubation period varies with temperature. Upon hatching, the larvae attack the developing nuts, where they complete their development. On reaching maturity the caterpillars leave the nuts and pupate in any suitable location. As noted by Jones and Davidson (1913) and Flanders (1926) some of the indi-

viduals of the first brood do not complete their development during the current season but carry over until the next year.

Second Brood. Moths of the second brood that do emerge begin to appear in late June, with heavy flights of moths encountered in July and August. These mate, lay eggs, and the larvae complete their development in the maturing nuts. These larvae overwinter in protected locations in silken cocoons, although in some seasons a few may give rise to a very small partial third brood (Quayle, 1921).

Possible Third Brood. Sometimes in late season, walnuts are attacked by very small caterpillars. It is not definitely known whether these are late second-brood individuals or the beginning of a partial third generation.

DESTRUCTIVENESS

The codling moth seriously infests the walnut, despite the fact that walnut is not the preferred host. Quayle (1918; 1926), Smith (1929), and Boyce (1935) have called attention to this fact of preference. Smith (1929) noted that the larvae were slow in entering nuts; Boyce (1935) also observed this behavior and further demonstrated that fewer individuals successfully attacked walnuts than apples. On apple, little time is lost in boring into the fruit, where the caterpillar is quickly protected within the apple from outside influences. Michelbacher (1945) observed that under conditions of relatively heavy infestations much caterpillar activity may be encountered about the base of nut clusters without much evidence of caterpillar penetration. Delayed entry and the fact that the codling moth is not as fond of walnuts as it is of apples tend to reduce the seriousness of the problem. It is certain that if the habits of the pest on walnuts were the same as they are on apples, control of the insect on walnut would be much more difficult.

Damage to walnuts varies with different localities and with different varieties. Boyce (1935), along with others, has observed a varietal susceptibility to attack. Among the most susceptible are the Payne and Concord varieties, while the Franquette and most late varieties exhibit a rather marked degree of resistance. However, in recent years situations have been encountered where Franquettes have been seriously attacked. In the absence of control, 50 per cent or more of a crop may be infested in the more susceptible varieties.

At the time the earliest caterpillars of the first brood are ready to infest the crop, the developing nuts of the Payne variety have an average cross-sectional diameter of about ½ inch. Up to the time the tips of the nuts begin to harden, most of the larvae enter the nuts at the calyx or blossom end (figs. 5 and 6). As a result, the majority of the first brood enters at this point. After the shells

Fig. 5. Nut halves revealing young caterpillars of the codling moth, and degree to which they had penetrated on May 18, 1943. (× 2.)

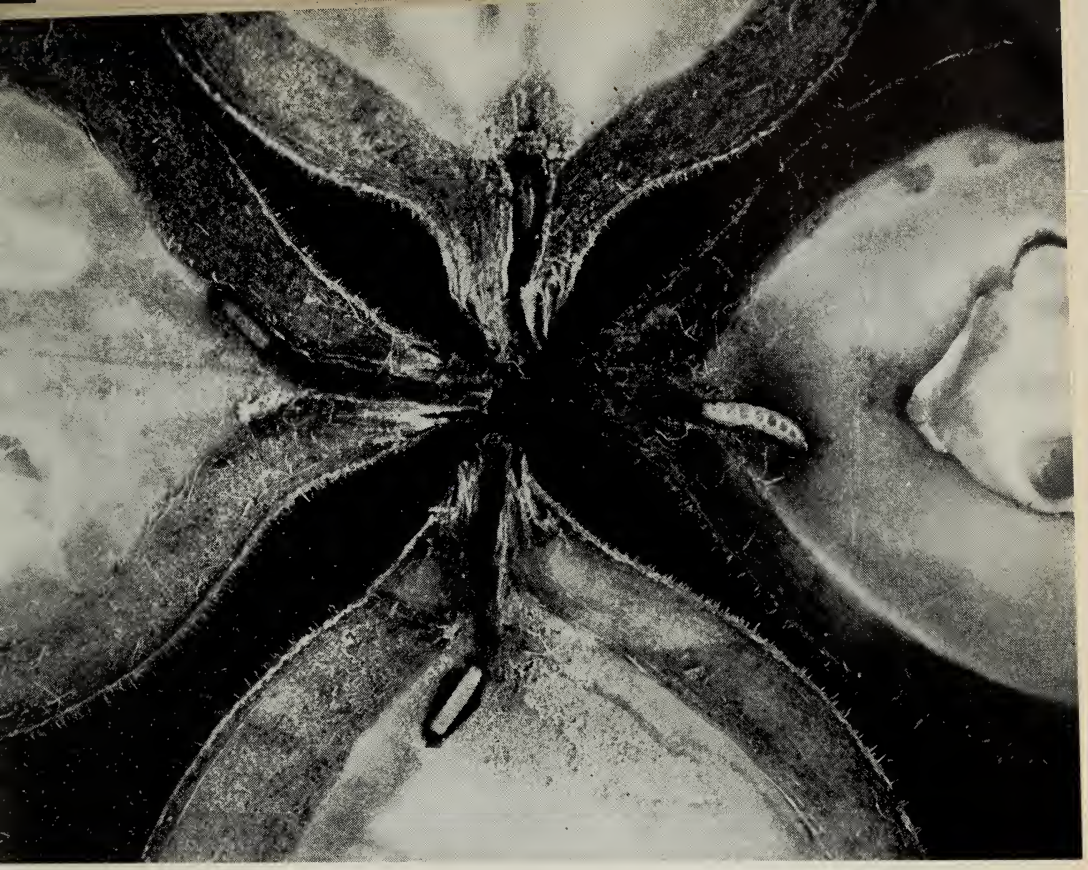


Fig. 6. Blossom end of nuts that were cut in half to show young caterpillars and degree to which they had penetrated on May 17, 1943. (× 5)

harden, more and more of the caterpillars penetrate the side or the base of the nuts. Late in the season most individuals bore at the base, especially if there are two or more nuts in a cluster.

All of the early infested nuts drop or dry up on the tree before harvest and although they represent a loss, they do not figure in the harvested crop. Usually around the middle of June there is a heavy drop of nuts that were infested early. In severe infestations the soil beneath the trees may be green with infested nuts.

If a larva infests a developing nut it tends to arrest development. This is well illustrated in figure 7, where all of the nuts shown are of the same age. The specimens were gathered in late June. The small ones in the lower row were infested in mid-May and had just recently fallen from the tree. To the left in the top row is a normal nut, and beside it are two rather recently infested ones. It is possible that these latter two were sufficiently advanced at time of infestation to remain in the tree until harvest. It is certain that nuts infested after the shells have fully hardened will hang in the trees until harvest and thus present a problem of being separated from the sound nuts

Injured nuts are more subject to infestation than are sound ones. The lower row in figure 8 shows nuts where the codling moth larvae gained entry through the lesions from walnut blight. The top row shows normal nuts where codling moth caterpillars penetrated the calyx end. Figure 9 shows a typical example

Fig. 7. Upper row: Walnut at left is without infestation, while other two show late infestation. Lower row: Recently dropped nuts that were infested in early May. (Photo taken June 25, 1948. Natural size.)

Fig. 8. Codling moth infestation in developing nuts. Upper row: Entry into sound nuts at blossom or calyx end. Lower row: Entry through lesion caused by walnut blight. (Natural size.)

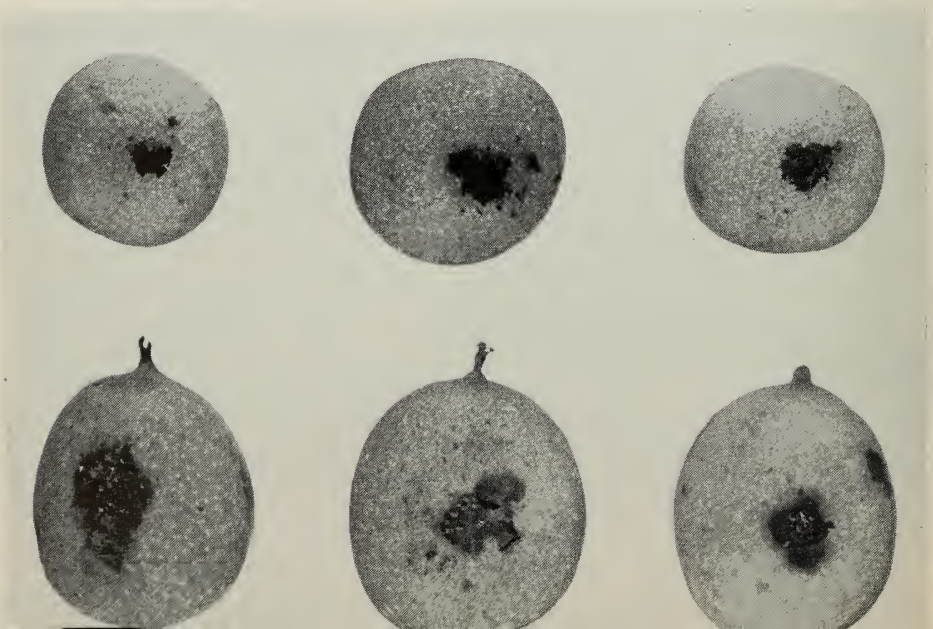


Fig. 9. Typical case of codling moth larva having gained entry at base of two developing nuts. (Somewhat enlarged.)

of the entry of a codling moth larva at the base of two developing nuts.

After the shell of the nut hardens, codling moth larvae rarely penetrate the shell. As a result of this, they complete their development on the husk, leaving the shell of the nut usually badly stained. Successful entry into the nut is usually obtained through the soft tissue at the stem end. Because the codling moth larva is able to penetrate the green husk, nuts that have been attacked by the pest usually show some staining of the shell. However, in late infestation after the husks have loosened or have cracked, it is possible for the pest to enter the nut without causing any staining.

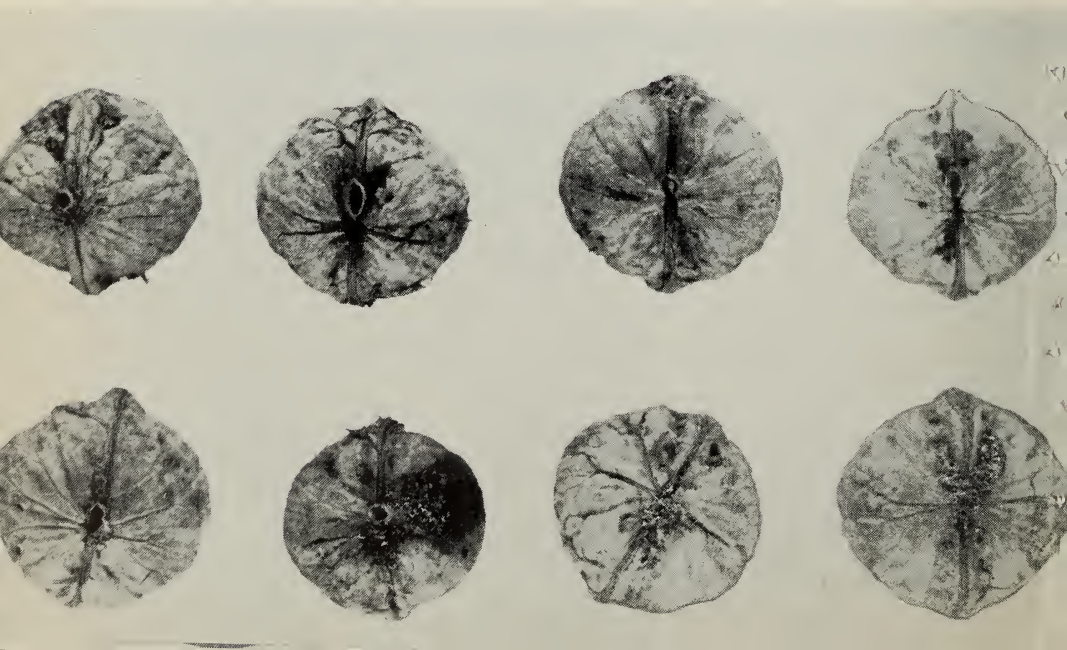
Where a caterpillar has gained entry to a nut, frass usually can be seen at the stem end. This, along with the characteristic staining of the shell is a sure sign that the nut is infested. Occasionally nuts are found that show where a caterpillar gained entry at a point other than the stem end. Characteristic types of injury encountered at harvest are shown in figures 10 and 11. In figure 12 is an infested nut that has been opened to show a caterpillar and the type of damage done. Usually by harvest many of the caterpillars have completed their development and have left the nuts.

The damage of shell staining done by the codling moth is easily distinguished from the damage done by other species of caterpillars infesting nuts. None of the latter species is able to penetrate the sound husk of walnuts and cannot attack the nuts until the husks have cracked. For this reason staining of the shell is never associated with their work.

Where the codling moth is a problem, a severe loss can be inflicted in a very short time. The rate of infestation by the first brood of caterpillars can be rapid, in less than a month attacking 20 to 30 per cent of the crop. This is well illustrated in figures 13 and 14 where the seasonal trend of infestation in untreated experimental check trees at Linden is plotted. The degree of infestation was determined by examining at random 80 nuts on each of seven trees. The trends of infestation as given in the figures show

Fig. 10. Characteristic injury by codling moth to walnuts at harvest. Upper row: Stem end infestation. Lower row: Typical staining caused by feeding of caterpillars on the green husks. (× 1¼)

Fig. 11. Types of injury by codling moth to nuts at harvest. Upper row: Nut at left shows exit hole at blossom or calyx end, while remainder of nuts show exit holes at stem end. Lower row: Typical injury where exit or entry has been made through soft tissue at stem end. (About natural size.)



a decline in the number of infested nuts that occur in June and early July. This happens because early infested nuts tend to drop from the trees and as the number of first-brood moths tapers off, the rate of drop exceeds the number of new nuts attacked. However, when the second-brood moths begin to appear the downward trend is reversed. This increase usually begins in July and tends to continue upward until harvest.

The seasonal trend in the infestation at Linden does not always follow the curves as shown in figures 13 and 14. In 1956 the infestation in early season was so light that the codling moth seemed not to present a problem. However, conditions became favorable for the pest in July, and a severe attack by the second brood occurred. By harvest approximately 50 per cent of the nuts had been infested. The trend of the infestation is illustrated in figure 15 and is certainly

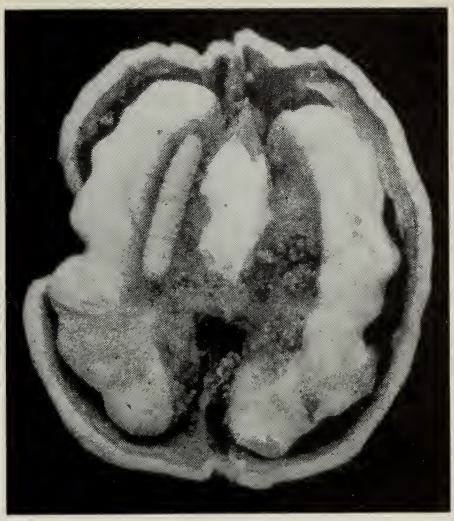


Fig. 12. Mature nut broken open to show characteristic damage caused by codling moth. (× 2)

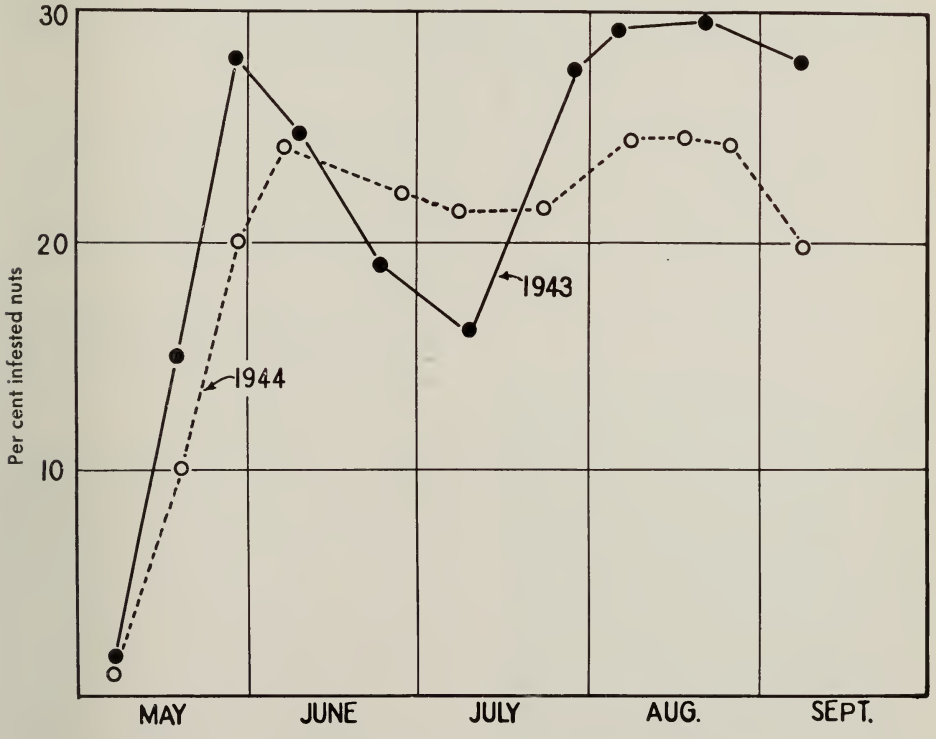


Fig. 13. Trend of infestation during growth of crop in check trees associated with experimental plots at Linden for 1943 and 1944.

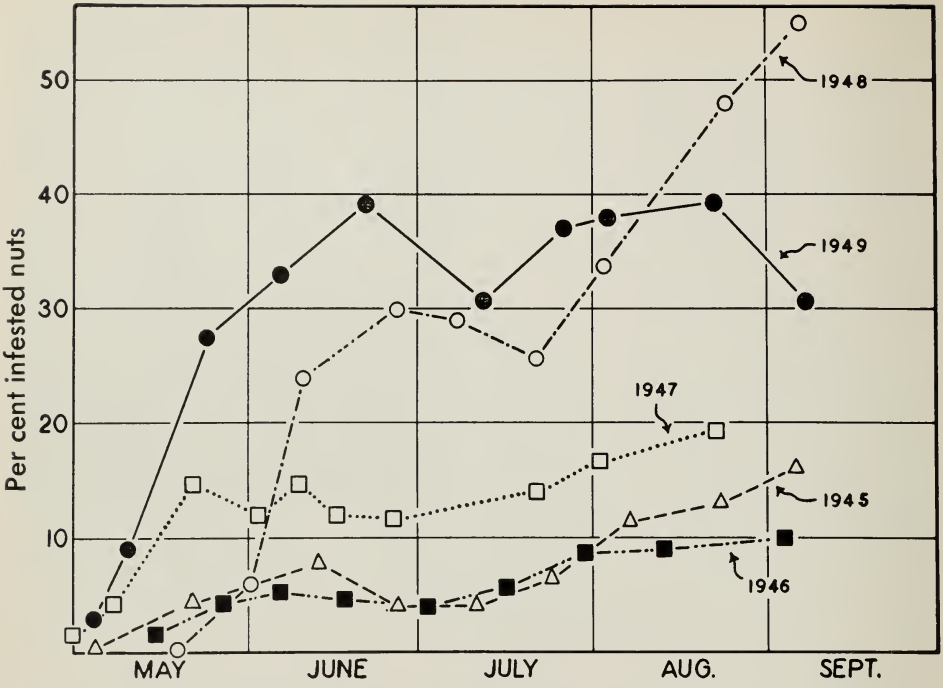


Fig. 14. Trend of infestation during maturing of crop in check trees associated with experimental plots at Linden for 1945 to 1949, inclusive.

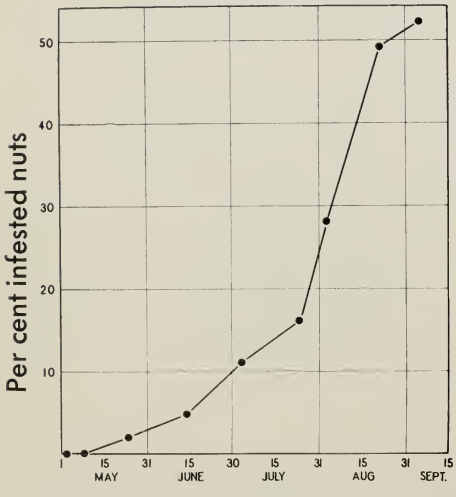


Fig. 15. Trend of codling moth infestation in the developing crop in check trees associated with experimental plots at Linden during 1956.

unlike any shown in figures 13 and 14. It is interesting to note that the conditions favoring the severe late-season infestation were general throughout northern California. The factors involved are not known.

In years where highly destructive populations were encountered, the loss of nuts exceeded 50 per cent of the crop.

CONTROL

There is a varietal susceptibility of walnuts to attack by the codling moth. Even with the susceptible varieties there is considerable variation in the degree of infestation. There are localities where little or no damage is done, while in others the damage is very great. The areas where the codling moth is likely to be of great concern are expanding. Once it has become established, a grower must be prepared to meet the situation year after year. Although many natural fac-

tors tend to suppress the codling moth population, if these fail to hold the pest below a troublesome level, artificial control measures must be used.

Natural Control

Like all other organisms, the codling moth is influenced by natural factors. These can be favorable or unfavorable and tend to regulate its population density. Under favorable natural conditions the codling moth is likely to present a more difficult problem of control than under unfavorable conditions. The fluctuations brought about by natural factors may be of considerable magnitude. This is well illustrated in figure 14, where the seasonal trend of infestation for untreated check trees at Linden is plotted for the years 1945 to 1949, inclusive. In 1946, the maximum infestation encountered was 10 per cent as compared with more than 50 per cent in 1948. The amount of environmental resistance encountered by the pest in the two years in question is largely responsible for the great difference in per cent of infestation.

Natural control falls into two main headings: (1) physical factors, and (2) biological factors. The first of these includes climate and weather. For example, an unusually hot spell or an extended cold, damp, moist period during mating and egg laying may exert a depressing influence upon the moth population. Heavy and prolonged winds at critical times may also produce unfavorable conditions. On the other hand, the physical factors may be extremely suitable to the pest and allow it to expand to its fullest extent. These factors are in constant operation and the effect exerted upon the population is very difficult to measure accurately.

Biological factors include such items as competition and natural enemies. The latter may be either predators, parasites, or diseases. Natural enemies are extremely important in suppressing the codling moth population. Michelbacher *et al.* (1950) pointed out the importance

Fig. 16. Bark removed from walnut tree showing overwintering codling moth larvae killed by a fungus, probably Beauveria bassiana (Balsamo) Vuillemin. (× 2)

of environmental resistance as a factor in the control of the codling moth on walnuts. Michelbacher, Middlekauff, and Hansen (1951) reported on investigations in which they found as many as 68 per cent of the overwintering codling moth larvae under the bark of walnut trees killed by a fungus disease. Larvae that have been eliminated by the disease are shown in figure 16. Numerous para-

Fig. 17. Walnut bark removed exposing puparia of a parasitic fly that has destroyed overwintering larvae of the codling moth. (× 2)

sites attack the pest. In figure 17 are shown the puparia of a parasitic fly that has destroyed overwintering larvae. Among the many predators attacking the codling moth are insects and birds.

Artificial Control

A number of farm practices are useful in suppressing infestations of the codling moth. These include sanitary measures, prompt harvest, and the application of insecticides. Although insecticides are of greatest concern, the other measures are important as supplements. Sanitary practices to aid in reducing the overwintering population should be encouraged. Infested nuts should be destroyed and, whenever possible, any spots where the larvae are likely to overwinter should be eliminated. The nuts should be removed as soon as they are mature in order to reduce the amount of infestation. Because nuts are subject to attack until late in the season, early harvest is advisable.

Chemical Control. Where the codling moth has become a problem, treatments are necessary for control. Spray programs against the pest have undergone changes. At first, basic lead arsenate was the principal material used. Among the early workers who contributed to the control program are Quayle (1926), Batchelor and Braucher (1929), Smith (1929), Boyce and Stanton (1933), Braucher and Boyce (1934), Boyce (1935), and Boyce and Bartlett (1941*b*). In a search for a more effective material than basic lead arsenate, Michelbacher (1945) carried on investigations which showed that standard lead arsenate in combination with a safener could be safely used under northern California conditions. A single treatment of standard lead arsenate gave almost as good control as did two sprays of basic lead arsenate. With the advent of DDT, a marked improvement in the control of the codling moth was obtained. The recent trends in control for northern

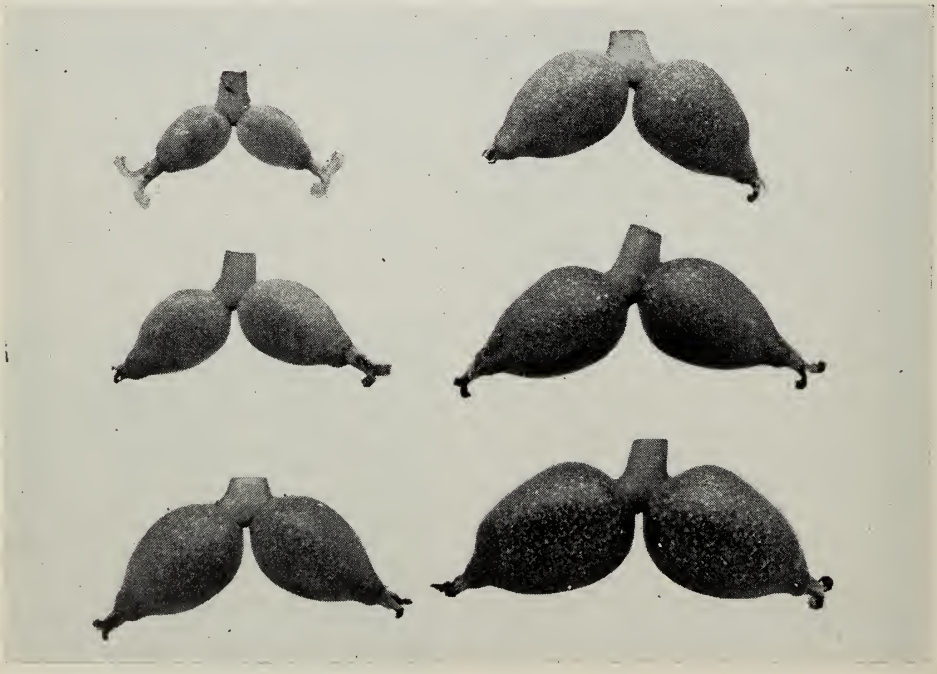


Fig. 18. Size of developing nuts (Payne variety) at time spray to control codling moth should be applied. (Natural size.)

California are reported by Michelbacher and Middlekauff (1949), and Michelbacher and Bacon (1953*c*), while the results for southern California are given by Ortega (1950*b*, 1951, 1952, 1953*a*, and 1954). At the present time the principal material used is DDT, although both standard lead arsenate and basic lead arsenate are still employed. The codling moth is showing some evidence of resistance to DDT. Observation of this kind stimulates a search for a better and more effective insecticide to use against the pest.

Timing of Application. The proper timing of spray applications to control the codling moth is a problem. The best results are obtained if the treatment is applied before the first brood of caterpillars begins to enter the nuts. Bait traps have been used (fig. 4) to determine the flight of moths, and these records have proved useful in timing spray applications. The treatment is applied at the first evidence of an increase in moth flight.

Michelbacher *et al.* (1950*a*) demonstrated that the size of developing Payne nuts could be used as a guide for timing the treatment to control the first brood of caterpillars. They found a correlation between the development of the nuts and the time the first caterpillars began to enter them. Their investigations showed that little or no infestation took place until the average cross-sectional diameter of the developing nuts reached about ½ inch (fig. 18). Therefore, it was safe to delay treatment until the average cross-sectional diameter of Payne walnuts reached ⅜ to ½ inch. This method of timing has proved to be highly satisfactory, and is now widely used.

Spray dates vary from locality to locality, and from season to season for the same district. In the warmer interior valleys, treatment is usually at least two weeks earlier than in the coastal areas.

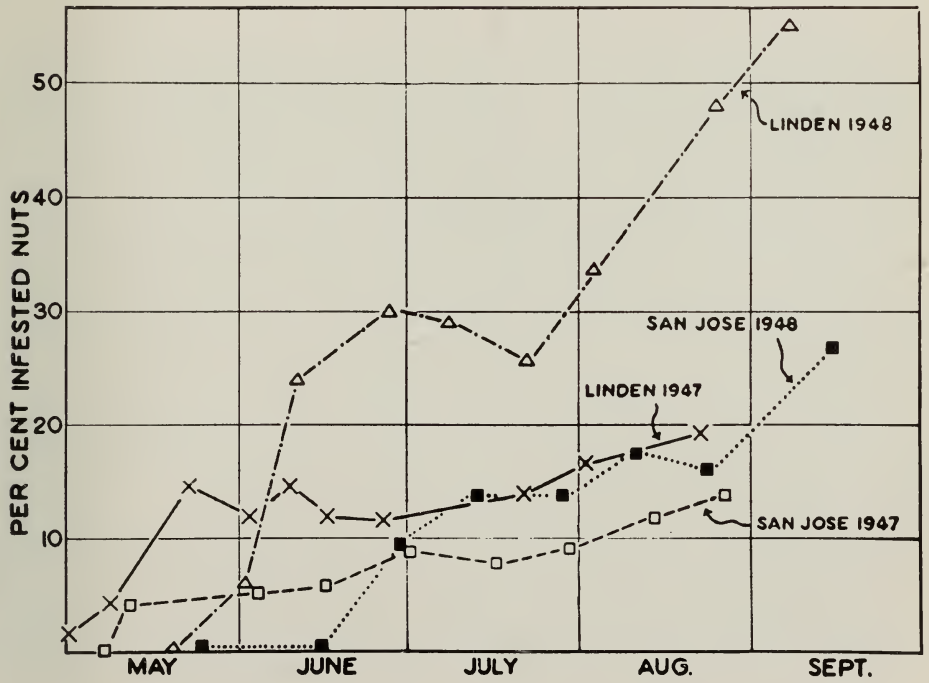


Fig. 19. Seasonal trend of infestation in developing nut crop in check plots at Linden and San Jose for 1947 and 1948.

This is well illustrated in figure 19, where the seasonal trend of infestation for 1947 and 1948 for Linden (interior), and San Jose (coastal) are plotted. It should be noted that the beginning of the infestation was later at San Jose than at Linden. Depending upon the season, the treatment date in the same locality may range over a period of more than two weeks. That a marked variation is brought about by seasonal conditions is well illustrated by the moth catches shown in figure 4, and by the trends of infestation given in figure 14. The time that a spray should be applied, depending upon the season, ranges from late April to almost the end of May. Whatever the seasonal variations, nut size appears to be the safe determinant of time to apply the treatment.

There are exceptions to the above timing. On occasions codling moth infestations have been encountered in Franquettes, a late variety. These infestations are believed to have been derived from late first- and second-brood caterpillars. This problem can be handled best by applying a treatment between June 15 and the end of June. Even with the Payne variety, there are instances where serious

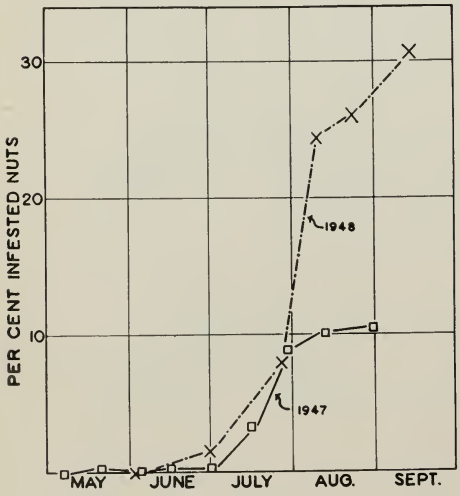


Fig. 20. Seasonal trend of infestation in maturing nut crop in unsprayed trees at Campbell for 1947 and 1948.

codling moth infestations seem to be associated with second-brood caterpillars. Investigations were conducted in an orchard at Campbell which showed very little evidence of infestation by the first brood of codling moths but where a serious situation developed after the first of July. The infestation is believed to have developed from second-brood caterpillars, although it is possible that a strain of codling moth is present that does not emerge in large numbers from the overwintering condition until late season. The seasonal trends in the infestation in this orchard for the years 1947 and 1948 are plotted in figure 20.

Number of Applications. Usually a single treatment applied with effective equipment under favorable weather conditions, before the first-brood caterpillars enter the developing nuts, should give adequate control for the entire season. Where these conditions are not met or where the past history shows a trend toward increased infestation in the harvested crop, a second spray during the latter part of June is advisable. However, before deciding to spray a second time make certain that the increase in infestation in the harvested crop is due to the codling moth and is not the result of an infestation of the filbertworm or the navel orangeworm. Spray programs directed against the codling moth are not effective against the filbertworm, although effective control of the codling moth will tend to lessen infestations of the navel orangeworm.

Investigations have clearly demonstrated that control of the codling moth is more difficult in an orchard located near another orchard where control measures are not adequate. Migrating moths from unsprayed orchards may make a second spray necessary in late June for satisfactory control of the second brood.

Both conventional (fig. 21) and air-carrier sprayers (fig. 22) are effective in applying sprays directed against the cod-

ling moth. Remember that for best results the treatments must be thoroughly applied.

Pests Increased by DDT. In order to prevent a serious increase in the walnut aphid population, an effective aphicide should be incorporated with DDT sprays directed against the codling moth. If a systemic aphicide is used in the first DDT spray, no aphicide may be needed with the second DDT spray applied to control the second brood of codling moths. The residual action of the systemic aphicide used in the first treatment may be sufficiently long-lived to insure control of the aphid following the second DDT treatment.

Applications of DDT also tend to induce increases in the spider mite and frosted scale populations. The adverse effect is held to a minimum if DDT is applied at a rate not to exceed 8 pounds of 50 per cent wettable powder per acre.

In some areas there are definite indications that the codling moth is developing some degree of resistance to DDT.

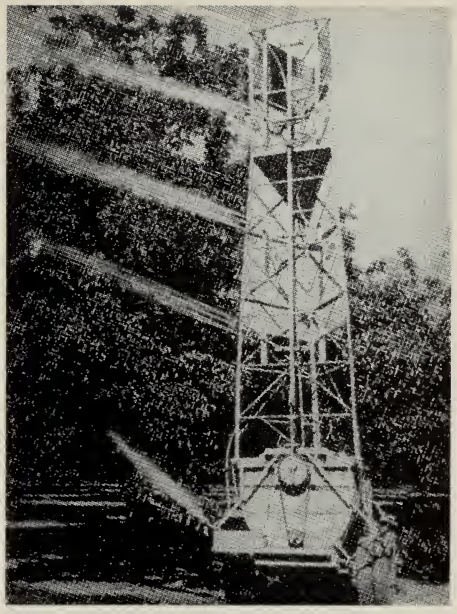


Fig. 21. An effective conventional sprayer for applying full coverage sprays. (Photo courtesy C. C. Anderson.)

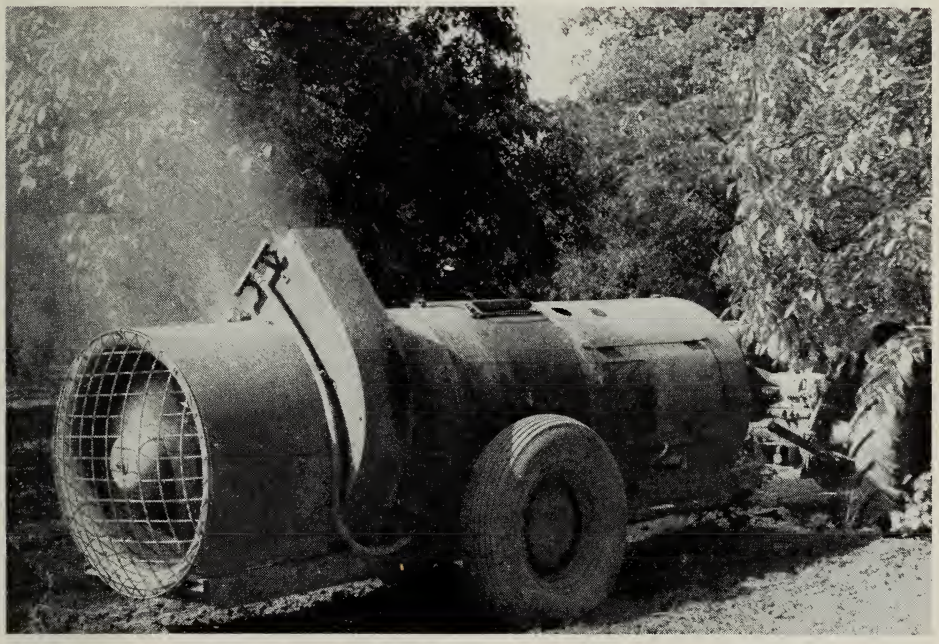


Fig. 22. An effective high capacity air carrier sprayer. (Photo courtesy C. C. Anderson.)

In these regions it may be necessary to increase the amount of DDT, 50 per cent wettable powder to 12 pounds per acre. Where this dosage is used, a grower must be prepared to combat spider mites and the frosted scale should their populations increase to a destructive level.

FILBERTWORM

The first record of the filbertworm, *Melissopus latiferreanus* (Wlsm.), infesting walnuts is that given by Keifer (1931) who stated that a light, but noticeable, infestation in walnuts was encountered in the Carmichael district of Sacramento County. The second notation of the insect occurring on walnuts in California is that given by Barrett (1932). Dohanian (1940) reported a single specimen as being reared from walnuts in the Willamette Valley in Oregon. Outside of these three records, the filbertworm apparently went unnoticed on walnuts until 1944, although it had developed into a serious pest on filberts in Oregon (Dohanian, 1940, 1944; Thompson, 1935, 1937, 1939, 1942).

In 1943, growers in the Sacramento Valley complained that the codling moth was causing serious damage to walnuts and asked that the situation be investigated. In response to the request, experimental work was undertaken in 1944 to determine if the treatments giving effective control of the pest at Linden in the San Joaquin Valley would also prove satisfactory in the Sacramento Valley. The studies were conducted in a Payne orchard near Live Oak. A serious caterpillar infestation developed in late season, and poor control was obtained. The characteristics of the infestation were unlike those caused by the codling moth and an investigation showed them to be principally due to the filbertworm and not the codling moth (Michelbacher, 1945). This definitely established the filbertworm as a *serious* and *destructive* pest of walnuts.

Fig. 23. Filbertworm adult.

DESCRIPTION

Like the codling moth, the filbertworm has four stages in its development: adult, egg, larva or caterpillar, and pupa.

Adult. The adult (fig. 23) at rest measures about ½ inch in length and has a wing spread approaching ¾ inch. It is about the same size as the codling moth, but differs from the latter in color and markings. The forewings are a reddish brown or dusky bronze. At about half their length, there is a broad, brilliant coppery band, and, nearer the tip, a narrower broken band of the same brilliant color. The hind wings are without a distinct pattern and are darker in color than those of the codling moth.

Egg. The eggs are laid singly on or near the larval host material. They are oval flattened, somewhat scale-like, and about one half the size of the head of an ordinary pin. In general appearance and size, the egg resembles that of the codling moth. When first laid, the eggs are waxy white, but as the incubation period advances, they darken with the developing embryo. Just before they are ready to hatch, the dark head and the body of the larva can be seen through the transparent shell of the egg.

Larva or Caterpillar. The bodies of newly hatched larvae are whitish, and the head and prothoracic shield are amber. In completing their development, the larvae cast their skin several times. The mature larva measures about ½

inch in length. The body is white and the head is clear amber. The white body and the clear amber head serve to distinguish the mature larva of the filbertworm from that of the codling moth larva, whose body is tinged with pink and whose head has a pattern of dark markings.

Pupa. On reaching maturity the larvae may stay where they developed or may crawl to some secluded spot to pupate. Before they pupate, a silken cocoon is constructed. Pupation occurs within the cocoon; at first the pupae are light amber, but darken with transformation to the adult stage.

SEASONAL LIFE HISTORY

According to Bacon *et al.* (1948), each year there are two, and a partial third brood of the filbertworm. The insects pass the winter as mature larvae in silken cocoons which may be found in a burrow of the food in which they developed or in other secluded or protected places. Dohanian (1940) observed the overwintering larvae in trash or rolled leaves under trees, on the surface of the ground, within the surface soil, in host fruits, and under other types of shelter.

In a later paper, Dohanian (1944) stated that hibernation usually occurred in tough, impervious cocoons within the first 2 or 3 inches of soil, but also occasionally in rolled leaves or other suitable trash on the ground.

Pupation of the overwintering larvae occurs in the spring from about mid-April through June. As is true of the codling moth, not all of the overwintering individuals emerge as moths the first season. Dohanian (1942*a*) reported that some specimens hibernate through two winters and a few larvae do not pupate and emerge as moths until after the third winter. This is certainly a provision of nature to insure the survival of the species.

Dohanian (1940) stated that the period of maximum emergence of adults from overwintering larvae was influenced by the host upon which the specimens had developed. He noted that individuals reared on wild hazelnuts emerged during June; those from filberts in July and early August; while moths from acorns did not appear in large numbers until August.

Although the insect can develop on many hosts, including acorns, fruit of Catalina cherry, wild hazelnuts, filberts, walnuts, and almonds, the principal host in California appears to be the "green apples" or galls of the California gall fly, *Andricus californicus* (Bassett), which are often found in great abundance on oaks. At the time the moths of the overwintering brood emerge, the galls are undergoing rapid development; after mating the females lay their eggs on or close to the galls. Upon hatching, the larvae bore into the galls, where they complete their development. When full grown, the larvae construct a tunnel to the margin of the mature gall, but do not completely penetrate the outer covering. After preparing the emergence tunnel, each larva moves back a short distance and spins a cocoon in which to pupate. If such a gall is closely examined, the thin covering left over the burrow appears as a small circular window. This, of course, is done to facilitate the emergence of the adult. Empty pupal cases are often seen protruding from the burrows after the moth has emerged.

Galls that have matured and hardened are no longer suitable as food. However, in the summer a second crop of galls is produced and these, along with other hosts, furnish material upon which the second and partial third broods develop. Overwintering larvae are derived from these broods.

Investigations by Bacon *et al.* (1948) have shown that the larvae of the filbertworm cannot develop on the green husks of walnuts, and apparently cannot penetrate sound husks until the husks begin to crack at maturity. Because of this, in-

festation in walnuts is believed to be due to migrations of moths that have developed on other hosts, principally oak apple galls. Although the insect cannot gain entry to merchantable walnuts until the husks begin to crack, bait-trap records have shown that adults are present in orchards throughout most of the growing season. The bait used consisted of one pint of Diamalt, one cake of yeast, and nine pints of water; the traps were serviced daily. The results of three years trapping in an orchard in the Gridley area are shown in figure 24.

DESTRUCTIVENESS

The filbertworm occurs throughout most of California. At the present time, it is of greatest concern on walnuts in the Sacramento and Napa valleys. It is likely to be destructive only in regions where its preferred host, the oak apple gall, is produced in abundance. Large populations develop in oak apples, and it is not uncommon to find a single gall infested with many larvae. Migrations of moths from this and other hosts, at the time walnut husks begin to crack, are responsible for the infestations that occur in walnuts (fig. 25). If the movement to walnuts is extensive, serious and destructive infestations are likely to result. All varieties of walnuts are subject to attack, but Payne especially seems to be preferred.

Because the larvae cannot penetrate the nuts until the husks begin to crack, the shells are not stained as they usually are when attacked by the codling moth. The absence of shell staining makes it very difficult to determine by external appearance whether or not a nut is in-

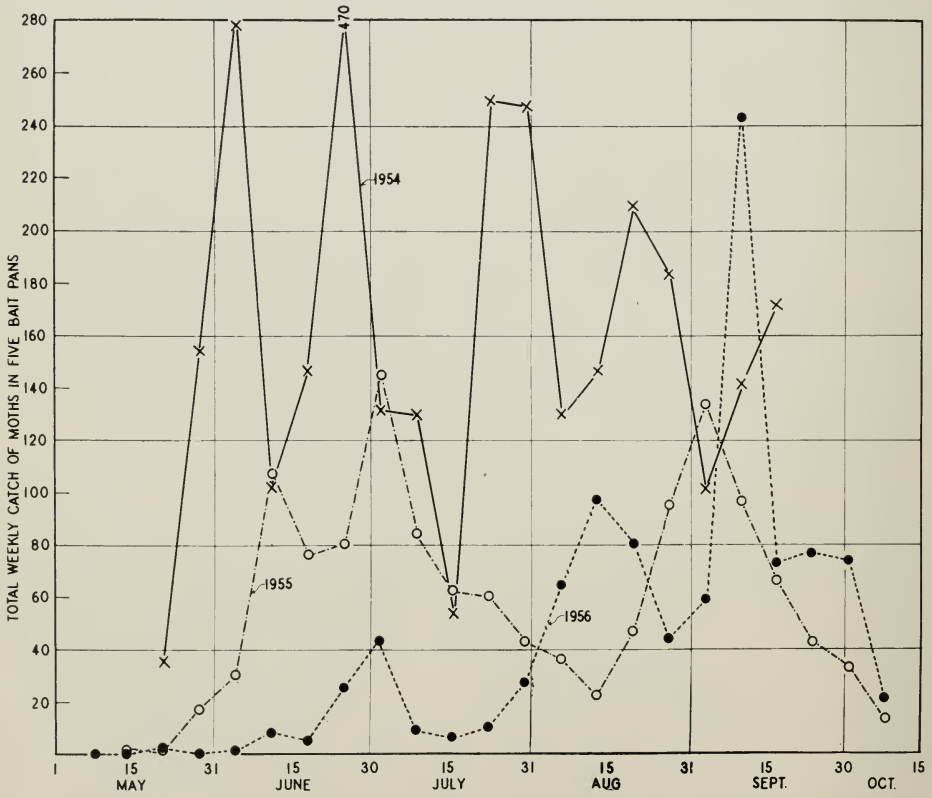


Fig. 24. Weekly catch of filbertworm adults in a walnut orchard near Gridley, California, 1954, 1955, and 1956.

fested. The only way to be certain is to open the nut. Because of the more or less hidden nature of the infestation, even a somewhat small population can cause much concern and annoyance if walnuts are used in the in-shell trade.

The degree of infestation increases as harvest is delayed. An examination of figure 24 shows that adult moths are present in an orchard well into the fall and, as a result, a short delay in gathering and curing the crop can mean a marked increase in the number of infested nuts. This is particularly true in seasons of large migrations of moths to the orchards.

An infestation within a walnut orchard may be uneven. Some trees are likely to be much more heavily attacked than others. Dohanian (1940), who conducted investigations of the pest on filberts, observed the same situation and stated that it would be unsafe to assume that a uniform infestation exists in any orchard.

The seriousness of the infestation varies greatly from year to year, on occasion being very destructive. It is believed that highly damaging populations developed in 1943. In 1944 infestations approaching 25 per cent were encountered (Bacon *et al.*, 1946). Beginning with 1945, the seriousness of the attack declined, but began to mount again in 1953. In 1954 a most serious outbreak occurred. A general increase in the number of nuts infested by the pest was observed throughout northern California. In areas where the filbertworm had a past history of destructiveness, infestations in the harvested crop that exceeded 30 per cent were not uncommon (Michelbacher *et al.*, 1955). Commenting upon the situation, Lockwood (1954) stated that the filbertworm, navel orangeworm, and the codling moth, were responsible for material losses to walnut growers in northern California during 1954 with the filbertworm the chief offender. Lockwood obtained his figures on infestation from caterpillars taken in crack tests at packing houses. These do not give the best picture of the overall situation because most of the codling moth larvae leave infested nuts before they are delivered to the packing plants. Actually, the codling moth was the most abundant pest in regard to the total number of nuts infested, but Lockwood's observations do point out the importance of the filbertworm outbreak in 1954. As reported by Michelbacher *et al.* (1956), the infestation of the filbertworm in 1955 was much less than that encountered in 1954. The infestation in 1956 exceeded that of 1955 due to a relatively heavy moth flight in late season. Based upon past performance, the infestation will probably show considerable variation, but serious infestations can be expected to develop from time to time during coming years.

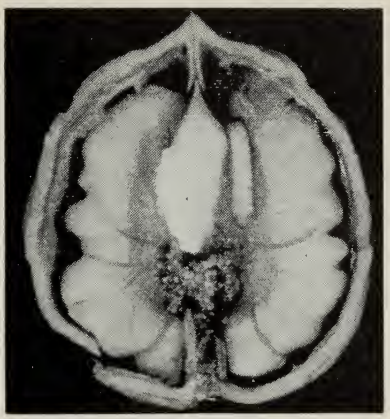


Fig. 25. Mature nut cracked open to show feeding and injury caused by cream-colored clear, amber-headed filbertworm. (× 2)

CONTROL

To the present time no satisfactory spray program has been developed which shows any real promise in controlling the filbertworm. Lead arsenate sprays have given the best results. They are applied in August and September when the filbertworm larvae are entering through the cracks in the walnut husks. Such sprays applied during the 1955 season reduced the degree of infestation by

about one half, but this is not enough reduction to give commercial control (Michelbacher *et al.*, 1956). Apparently, the progressive cracking of the hulls breaks any protective spray residue covering and allows many of the larvae to penetrate the nuts without coming in contact with the poisonous film deposited by the treatment.

Because there is no satisfactory spray treatment to be recommended, a grower must rely upon natural control and cultural measures to check serious infestation by the filbertworm.

Natural Control

It is believed that the wide fluctuations occurring in the infestation of walnuts by the filbertworm are possibly due to the action of natural enemies. Michelbacher and Hitchcock (1955) indicated that natural enemies have played an important role in reducing infestations of the pest. In a later paper Michelbacher *et al.* (1956) indicated the possibility of natural enemies exerting an important influence, and in some years parasites may reduce the moth population to such an extent that few migrate to walnut orchards. The filbertworm is known to be attacked by many natural enemies. Dohanian (1940) reported more than six hymenopterous parasites of the larva and one dipterous pupal parasite. In a later paper Dohanian (1942*b*) increased the number of parasites encountered by 13. It is not difficult to believe that the many natural enemies might well reduce the population of the filbertworm in some years to a noneconomic level.

Cultural Control

Because all infestations of merchantable walnuts take place after the husks crack, every effort should be made to harvest the crop just as soon as it is ready. It should be remembered that the longer the nuts remain in the trees the greater the opportunity for them to become infested. A delay in harvest of a week or two may mean a marked increase in the amount of infestation. Further, the nuts should be dried as soon as they are harvested, for experiments have been conducted demonstrating that the larvae of the filbertworm are unable to develop on walnut meats once they are thoroughly dried. Rapid drying also kills the very small larvae that gain entry before they have opportunity to do sufficient damage to be detected.

In ordinary seasons early harvest and rapid drying of the crop should reduce the infestation of the filbertworm below an economic level. However, in an outbreak year, such as that of 1954, these measures are not sufficient to reduce the infestation to such a point; therefore, it is hoped that a successful spray program can be developed to take care of the situation when such conditions develop.

In order that the trend of moth populations can be followed, it is recommended that bait-pan records as shown in figure 4 be maintained each year. Such records can be utilized to forecast the seriousness of the infestation in advance of harvest.

Because of the difficulty in determining whether or not nuts are infested with the filbertworm, every effort should be made to control the codling moth even though the infestation of the latter may be light. This is recommended because the combination of infested walnuts resulting from the two pests may seriously lower the value of the crop.

NAVEL ORANGEWORM

The navel orangeworm, *Paramyelois transitella* (Walk.), which is primarily a scavenger, was described by Dyar in 1914 as *Myelois venipars* from cull oranges taken in the vicinity of Hermosillo, Mexico. In 1921 it created considerable concern when it was found infesting Washington Navel oranges in the Salt River Valley region of Arizona. However, investigations showed the larvae

to be a secondary pest of oranges because they attacked fruit infected with *Alternaria* rot or fruit otherwise injured. Larvae were seldom taken from oranges that appeared to be sound.

According to Armitage (1947) the first collection of the navel orangeworm from walnut in California was made in 1943. The best account of the insect on walnuts is that given by Ortega (1950*a*). He stated that in 1945 there was a record of the insect being collected in the field from walnuts in Orange County, and that by 1946 it had become a threat to the walnut industry in southern California. Since that time it has spread northward and now occurs over most of the walnut-producing regions of the state.

DESCRIPTION

Like other moth pests of walnuts the navel orangeworm has four stages in its development: adult, egg, larva or caterpillar, and pupa.

Adult. The adults (fig. 26) at rest measure about $\frac{5}{8}$ inch in length. They are silvery gray. The forewings are ornamented with a dark pattern of black, irregularly narrow to broadly wavy lines.

Eggs. The flattened oval eggs, which superficially resemble those of the codling moth are usually laid singly, although two or three may be found in a group. They are slightly smaller than the head of a pin. The major axis measures about 0.04 inch while the minor axis is approximately 0.027 inch. When first laid, the eggs are pearly white, but turn red in from 24 to 48 hours as the embryo develops.

Larva or Caterpillar. The newly hatched larvae measure about 0.062 inch in length, are pinkish or, in some cases, almost red and to the unaided eye resemble the larvae of the codling moth. The color of the developing larvae appears to be influenced by the kind of food eaten. When full grown the larvae (fig. 27) are whitish or possibly pinkish. They measure about $\frac{1}{2}$ to $\frac{3}{4}$ inch in

Fig. 26. Adult of the navel orangeworm. (× 6¼)

Fig. 27. Mature larva of the navel orangeworm. Note two opposing crescent-shaped pigmented areas on second thoracic segment. (× 5)

length. The larvae can be distinguished from those of the codling moth or the filbertworm by the two opposing crescent-shaped pigmented areas on the dorsal surface of the second thoracic segment, from which setae arise. These opposing chitinous areas are clearly shown in figure 27. Upon reaching maturity the larvae spin a rather tight, tough, closely woven, silken cocoon in which they pupate.

Pupa. In the field, pupation usually occurs within or close to the infested nut. However, under conditions of storage the caterpillars often leave the walnuts to pupate, and it is not uncommon to find mature larvae in the vicinity of, and moving over, the outside of sacked nuts. The pupae at first are light amber but darken with transformation to the adult stage.

SEASONAL LIFE HISTORY

According to Bacon and Wade (1954) the navel orangeworm is primarily a field-inhabiting insect. It will breed in storage, however, and cultures have been maintained in the laboratory without any serious difficulty. Each year there are a number of overlapping generations. The insect typically is a scavenger, but under favorable conditions attacks sound walnuts and almonds. The navel orangeworm breeds principally in mummified fruits and in nuts left on the ground or hanging on the trees. Among its hosts as listed by Ortega (1950*a*) are almond, apricot, apple, fig, jujube, loquat, mulberry, orange, peach, persimmon, plum, quince, and walnut.

The adults are seldom seen in the field, but they are frequently observed during the harvest period resting on the walls of dehydrater sheds or in packing houses. On occasions they have been taken in codling moth bait pans or in pans set out to trap adults of the walnut husk fly. Depending on weather conditions, a life cycle takes from five to more than nine weeks. In the field the insect reaches the greatest numbers in the late summer and fall.

According to Michelbacher and Ross (1955) the pest is able to survive winter conditions out of doors as larvae in various stages of development. Where infestations occur, an examination of old nuts hanging in the trees or on the ground will usually disclose larvae. In the spring and summer, breeding continues in these sources and in the nuts of the current season's crop that have been infested by the codling moth. These unharvested walnuts infested with navel orangeworm larvae serve as a reservoir of infestation for the following year (Ortega, 1950*a*). When these individuals complete their development and emerge as adults the females prefer to deposit their eggs in or near the frass pushed out by the codling moth larvae. However, in the absence of infestations by the codling moth, the females will lay eggs on sound husks which the larvae are unable to penetrate. Late in the season when the husks begin to crack as maturity is reached, the larvae can infest the nuts where they gain entry through the soft, pithy tissue at the basal end. Also, after the husks split, eggs may be deposited on the walnut shell as well as on the husks.

Both Ortega (1950*a*) and Michelbacher (1956*b*) have observed that nuts infected with walnut blight or those with sunburned areas are not attractive to the navel orangeworm and apparently play no important part in its ecology. It is the previous year's nuts that carry the pest through the winter, spring, and into the summer until the nuts of the new crop are infested by the codling moth or until the husks begin to crack so that the larvae can gain direct entry to the nuts. Infestations may carry over on other hosts and there is always the possibility that infestations in walnuts may arise through migrations from these sources. This appears to be particularly true where walnuts are grown near infested almond orchards or other crops where quantities

of mummified fruits occur. For this reason walnuts from trees grown near homes are often more heavily infested than are those grown in large orchards.

DESTRUCTIVENESS

Sound walnuts are free from attack until the husks begin to crack. From this time on the nuts are subject to invasion and if infested nuts are placed in storage without fumigation, breeding and further infestation will occur. Because the larvae are unable to penetrate the nuts until the husks begin to crack, they do not stain the shell. In this, the infestation resembles that of the filbertworm. The absence of shell-staining makes it very difficult to determine by external appearance if a nut is infested. Because of this characteristic, the only sure way to detect infestation is to crack the nut open. The hidden nature of the infestation creates a very annoying situation with walnuts used in the in-shell trade.

The degree of infestation increases as the harvest is delayed. Where a source of moths is present, as the crop matures, a highly destructive population will develop if the walnuts are not harvested as soon as they are ready.

It is not uncommon for more than one larva to attack a single nut (fig. 28). Boyce (1947)[3] reported finding as many as 37 caterpillars in an infested walnut and it is not unusual to find eight or nine larvae of various sizes in a nut. The finding of more than one caterpillar in a nut at harvest is almost a sure sign that it is infested with the navel orangeworm. This might not be true with nuts in storage since multiple infestation of a nut by caterpillars of the Indian-meal moth or the Mediterranean flour moth—both of which are strictly stored-product pests—frequently occurs.

Quantities of webbing are produced by the larvae of the navel orangeworm, usually with large amounts deposited in infested nuts. Where serious infestations occur in storage, nuts may be webbed together; if they are in sacks the latter are often webbed over and heavily contaminated with cocoons spun by the larvae.

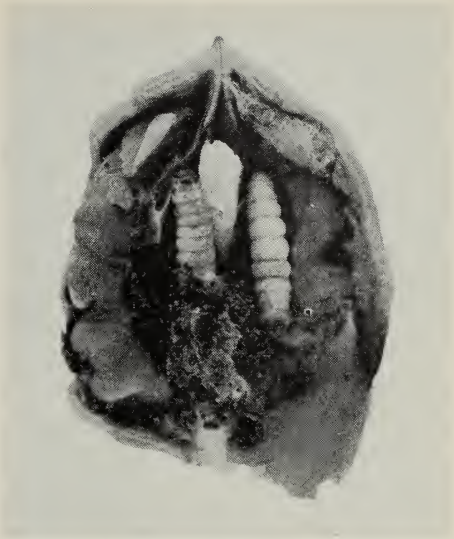


Fig. 28. Walnut cracked open, showing type of damage done by caterpillars of navel orangeworm. (× 1½)

According to Ortega (1950*a*) the navel orangeworm infestation on walnuts in southern California reached its maximum proportions in 1947, and has declined since. The infestation in northern California started later than that in southern California. In northern California it was of increasing concern until 1955. In that year the infestation turned downward, but in 1957 the trend was upward.

Attack by the navel orangeworm is favored by codling moth infestations. The problem mounts as the damage caused by the latter insect increases.

CONTROL

To the present time no specific, effective spray program has been developed against the navel orangeworm. Therefore, control of the pest in the field is largely dependent upon natural control and preventive measures.

[3] Boyce (1947). Unpublished data.

Natural Control

Because the navel orangeworm is a relatively recent pest of walnuts, not a great deal is known about its natural control. It does not appear to be attacked by many natural enemies. Ortega (1950) has reared the parasitic wasp, *Microbracon hebetor* (Say), from the larvae.

Preventive Measures

Practices that aid in suppressing damage are: (1) effective control of the codling moth where it is a pest; (2) early harvest; and (3) sanitation.

Because the navel orangeworm is a scavenger, uncontrolled infestations of codling moth encourage its attack. This fact has been noted by Ortega (1950*a*), Michelbacher and Ross (1955), and Michelbacher (1956*b*). Ortega (1950*a*) stated that the danger of a serious infestation by the navel orangeworm can be greatly reduced by using effective control measures for the codling moth. He noted that this was particularly evident when groves in southern California were effectively treated with DDT. Satisfactory control of the codling moth is desirable because nuts infested by it furnish a source of food upon which the navel orangeworm can increase. As a result, a large population of navel orangeworm moths may be present to attack the crop as it reaches maturity and the husks begin to crack.

As is true of the other pests discussed, early harvest is important, because the navel orangeworm cannot enter sound nuts until the husks begin to crack. Therefore, the opportunity for the nuts to become infested increases the longer they are left on the trees or on the ground. The navel orangeworm population expands as the season advances.

Sanitary practices should be followed that will tend to break the food chain carrying the navel orangeworm from one crop to another. Field sanitation will help. Remove the nuts and sticktights as completely as possible from the trees. Destroy the crop residue on the ground by cultural means before midspring. Also destroy well ahead of the growing season, either by burning or by cultivation, culls and other waste accumulating about hullers, dehydrators, barns, and other buildings.

Chemical Control

Lindgren[4] demonstrated that in 36 regions of infestations the navel orangeworm could be successfully destroyed by fumigating the daily receipts of walnuts at the local packing house with methyl bromide. This was first accomplished under tarpaulins until such time as gastight fumigation chambers could be constructed. The methyl bromide fumigation procedure proved to be very effective not only for the navel orangeworm but for other stored-products pests and is now a standard practice.

During the years of peak activity of the navel orangeworm the walls, ceilings, floors, bins, and other surfaces in the packing houses were sprayed with DDT (Boyce, 1946)[5] prior to the delivery of the first walnuts for processing. This was very effective in killing the adults which emerged from the sacked walnuts, awaiting fumigation, and rested on these surfaces in tremendous numbers. This procedure minimized the possibility of reinfestation of cull walnuts which are held in the packing houses for somewhat longer periods than the merchantable walnuts.

RED-HUMPED CATERPILLAR

The red-humped caterpillar, *Schizura concinna* (A. and S.), is an important defoliator of walnut trees. It was recorded as a pest of this crop as early as 1913 (Vosler, 1913). It occurs over much of the walnut-producing sections

[4] Lindgren, D. L. 1947. Unpublished data and correspondence.

[5] Boyce, A. M. 1946. Unpublished data and correspondence.

of California and is most destructive in the warm central valleys.

DESCRIPTION

There are four stages in the development of the red-humped caterpillar: adult, egg, larva or caterpillar, and pupa.

Adult. The adult moths are reddish brown to gray and have a wing expanse of from 1¼ to 1⅜ inches. The forewings are reddish and the hind wings are lighter and gray in color. Little or no markings occur on the wings of the female, while a color pattern occurs on the forewings of the male. The antennae of the female are filiform and those of the male are plumose.

Eggs. The adult female lays her almost spherical, pearly white eggs in groups of from 25 to 100 on the underside of the leaves (fig. 29). The eggs are about 1/16 inch in diameter.

Larva or Caterpillar. The mature caterpillars measure about 1½ inches in length. They are rather striking in appearance. The base color is yellow and the body is marked with longitudinal reddish and white stripes. The head and the fourth segment are bright red. On the fourth segment is a hump. From the body segments black tubercles arise. The two on the hump are the most prominent.

Pupa. The pupa is a rich dark amber, enclosed in a silken cocoon which is constructed in the soil or the debris covering it.

SEASONAL LIFE HISTORY

Although the red-humped caterpillar is a pest of a number of crops, the seasonal life history is not thoroughly understood. It needs further investigation. In California there are at least three broods, although Hoffman (1953) has said there are five generations each year in northern California.

The winter is passed as larvae in the prepupal stage in silken cocoons.

Fig. 29. Hatching larvae of the red-humped caterpillar on underside of a walnut leaflet. (× 1½)

The period of pupation occurs in the spring and the moths begin to emerge in May. Mating and egg laying take place and the first larvae soon appear. The caterpillars complete their development in May and June, drop to the ground, and pupate either in the soil or the debris. Moths emerge in July and August. They mate and lay the eggs that give rise to the summer brood. The caterpillars from these eggs upon completing their development drop to the ground, burrow into the soil, and construct silken cocoons in which some probably pass the winter as prepupal larvae, while others complete their development and give rise to a third brood. The larvae of this brood complete their development in September and early October. They then drop from the trees, burrow into the soil and construct silken cocoons in which the winter is spent as larvae in the prepupal stage.

DESTRUCTIVENESS

A number of crops besides walnuts are attacked. These include apple, apricot, plum and prune, as well as a number of nonorchard plants. Most damage is done by the summer brood, and trees may be completely defoliated (fig. 30) if serious infestations are left unchecked. More often, serious damage is confined to scattered branches as shown in figure 31. Under conditions of destructive infestations the soil beneath the trees may be covered with droppings from the caterpillars.

At hatching, the young caterpillars feed on the underside of the leaves. They are gregarious in habit and feed in colonies (fig. 32). As they increase in size individuals tend to disperse. The larger caterpillars consume all the leaf area except the woody veins.

Where defoliation occurs the developing nuts are subject to sunburning. Further, where there is serious defoliation early enough in the season, a large amount of new growth may be stimulated, which does not have time to mature and therefore is subject to winterkill.

CONTROL

Many factors enter into the control of the red-humped caterpillar. It is held in check by natural factors and artificial measures.

Natural Control

Both physical and biological factors are important in suppressing damage by the red-humped caterpillar. That physical factors exert a controlling influence is shown by the fact that damage from the pest tends to be limited to the interior

Fig. 30. A young walnut orchard that has been defoliated by the red-humped caterpillar.

Fig. 31. A small branch of a walnut tree which has been defoliated by the red-humped caterpillar. Note that all but the woody veins are eaten.

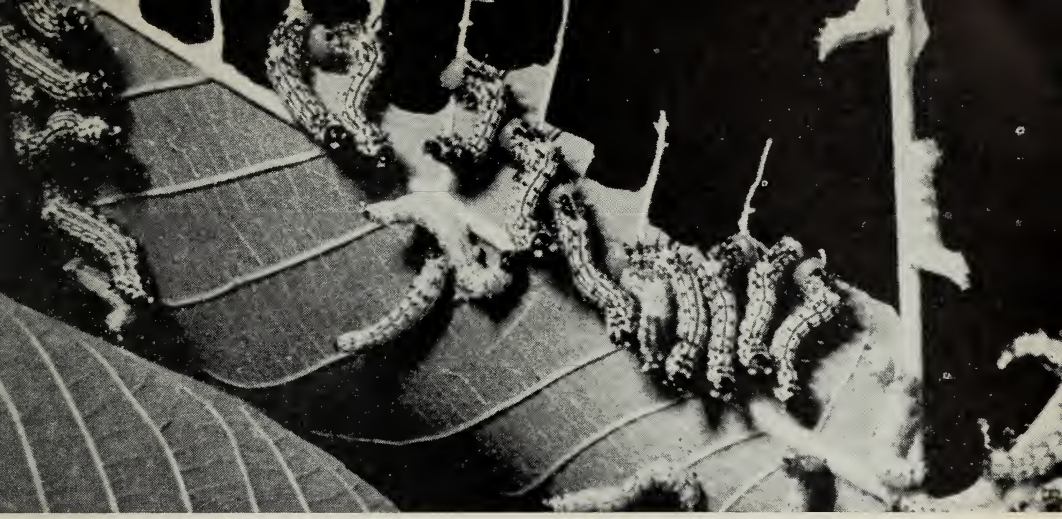


Fig. 32. Gregarious feeding habit of the red-humped caterpillar. (× 1½)

valleys. The climate of the coastal regions usually does not favor the development of destructive populations. Weather conditions within regions where the red-humped caterpillar is a pest play a part in regulating the population. In this regard Hoffman (1953) stated that there seems to be a direct correlation between winter temperatures and the red-humped caterpillar population that overwinters and emerges in the spring. He believed that an outbreak of the pest is favored by warm winters.

Biological factors are extremely important in controlling the red-humped caterpillar. It is attacked by many natural enemies of which parasites appear to be the most effective. It is believed that biological agencies are responsible for suppressing the pest population to a non-economic level in many orchards or even in districts.

A number of ichneumonid parasites attack the pest and one of these, *Hyposoter fugitivus* (Say), is shown in figure 33. Another of the many wasp parasites

Fig. 33. Red-humped caterpillars that have been destroyed by Hyposoter fugitivus (Say), one of the several wasp parasites of the pest. (× 2)

Fig. 34. A red-humped caterpillar which has been destroyed by a braconid parasite, one of the many wasp enemies of the pest. (× 4)

is the braconid which has killed the red-humped caterpillar shown in figure 34.

Artificial Control

Cultural methods as well as insecticides are employed in checking damage by the red-humped caterpillar. Because of their gregarious habits, colonies can be removed from the trees by cutting out the infested twigs, or they can be killed with a torch.

Because the red-humped caterpillar is a defoliator it is easily killed with relatively small dosages of insecticides, such as DDT and lead arsenate. It is seldom found in an orchard treated to control the codling moth.

FRUIT TREE LEAF ROLLER

The fruit tree leaf roller, *Archips argyrospila* (Wlk.), is widely distributed throughout California. Besides attacking walnuts, it infests a great many plants including most of the important orchard crops as well as many shade trees and ornamentals. The insect is primarily a defoliator although it can and does seriously injure young developing fruits.

Fig. 35. Adult of the fruit tree leaf roller. (× 7)

Fig. 36. Ventral, dorsal, and lateral views of mature larvae of the fruit tree leaf roller. (× 3½)

DESCRIPTION

The insect has four stages in its life cycle: adult, egg, larva or caterpillar, and pupa.

Adults. The adults (fig. 35) at rest measure about ½ inch in length and are bell shaped. With wings spread they measure ¾ to 1 inch. The basic color of the forewings is a more or less rusty brown with lighter and darker markings. With the exception of the outer lighter margin, the hind wings are fawn colored.

Eggs. The eggs are laid in irregular flat masses that are covered with a grayish cement-like material which darkens with time.

Larva or Caterpillar. The full-grown larva (fig. 36) measures about ⅞ inch in length. The head is amber and the body is light green with darker upper surface. The dark color is most pronounced at the anterior end. Different individuals may show some slight variations in shade of color. The dorsal sur-

face of the larva is sparsely clothed with rather long hairs. When disturbed, the larva wiggles violently and retreats into the leaf-fold it has constructed or drops to the ground.

Pupa. The amber-colored pupa is found enclosed in a light webbing within a leaf-fold.

SEASONAL LIFE HISTORY

The fruit tree leaf roller has but a single generation each year. The winter is passed in the egg stage. The eggs are laid in masses on the bark of the trunk and limbs. They hatch in the early spring and the larvae begin to feed on the developing leaves and nuts (fig. 37). The leaflets may be completely eaten and are rolled and tied together with webbing to form hiding places. When mature the larvae roll leaflets as shown in figure 38 and in these they pupate within a light webbing. Larvae reach maturity during April and early May. The pupal period is of rather short duration after which the adults emerge, mate, and lay the egg masses that remain on the trunks and branches throughout the summer, fall, and winter.

Fig. 37. Early season damage to foliage and developing nuts by the fruit tree leaf roller.

DESTRUCTIVENESS

In most areas the fruit tree leaf roller is not destructive. Some scattered injury can usually be found. Injury is likely to be most noticeable near the trunk and larger limbs. Under conditions of severe infestation, trees may be nearly defoliated. Damage occurs in the early season and is most pronounced during April and early May.

CONTROL

The fruit tree leaf roller is attacked by natural enemies, which are apparently important in suppressing the population. Where destructive populations develop they can be controlled with DDT or lead arsenate sprays. Seldom if ever are treatments needed in northern California. To be effective the treatments should be ap-

Fig. 38. Leaf-folds or rolls constructed by the fruit tree leaf roller. These are held together with webbing, and within such rolls the mature larvae pupate in a light webbing. (About half size.)

plied in early April. It is interesting to note that the fruit tree leaf roller completes its development before the time comes to apply a spray to control the first brood of codling moth. For this reason treatments directed against the codling moth are ineffective against the larvae of the fruit tree leaf roller.

FALL WEBWORM

The fall webworm, *Hyphantria cunea* (Drury), is a common caterpillar pest throughout the interior valleys. Besides attacking walnut, it attacks a wide range of forest, shade, deciduous fruit trees, and certain deciduous ornamental shrubs.

DESCRIPTION

The following description has been largely derived from Essig (1926). The adults have a wing spread of about 2 inches. They are pure white, clothed with long soft hair, with or without a few black spots on both sides of the wings. The antennae are black and white, and the abdomen is often yellow with black spots on the top and sides. The eggs are globular and white or golden yellow and are laid in masses, usually on the undersides of the leaves. The mature caterpillars measure about an inch in length. They are pale yellowish brown or grayish, and are clothed with long whitish hairs which arise from black and orange tubercles. Usually there is a yellow stripe along the side and a dusky one along the back. The amber pupae are enclosed in dark-brown cocoons.

SEASONAL LIFE HISTORY

The fall webworm has but a single generation each year. The winter is passed as pupae within cocoons that are attached to the trunk of trees or to any other object in a secluded place. The moths emerge in late spring or early summer and lay their eggs in batches during June and July. The eggs hatch within a week to 10 days. The caterpillars are gregarious, and feed within the large silken webs which they spin. As development progresses, the web is enlarged until, before the caterpillars have completed their growth, it may enclose an entire branch. The dense webbing, which is very characteristic, is easily spotted at a distance. The caterpillars complete their development in late summer or early fall, at which time they spin cocoons, and transform into the overwintering pupae.

DESTRUCTIVENESS

Infestations by the fall webworm are usually rather spotty. They seldom do any great damage.

WALNUT SPANWORM

The walnut spanworm, *Coniodes plumogeraria* (Hulst), is a caterpillar pest which on occasions has been reported as injuring walnuts. The pest normally feeds on live oak; besides walnut, it attacks apple and prune as well as other fruit trees.

DESCRIPTION

The following description of the walnut spanworm has been taken from Flanders (1924). The female is a brownish-gray, wingless moth measuring about ½ inch in length. The underside of the abdomen is light gray and the upper surface is tinged with bronze. The male is winged and has a wing spread of about 1½ inches. The wings are silvery gray, and each forewing is transversed by four narrow wavy brown bands. Each hind wing is characteristically marked with a brown spot near the center. The eggs are oval and slightly ridged. When first laid they are irridescent bronze but before hatching they become light blue. The newly hatched larvae are black with white patches along the sides. When mature, the larvae measure about 1 inch in

length and are a light pinkish gray with darker markings. They have two prolegs and in crawling arch their back—thus the common name spanworm. Pupation occurs within the soil.

SEASONAL LIFE HISTORY

The walnut spanworm has but one generation each year. The adults emerge in February and March. After mating, the female lays her eggs in masses on the twigs and branches. The larvae complete their development in April and May and drop to the soil to pupate. Pupation occurs in the soil at a depth of 2 to 4 inches about the base of the trees.

DESTRUCTIVENESS

Although the pest occurs throughout the Pacific Coast states, damage to walnuts has been limited to southern California. Essig (1926) reported a large walnut orchard in the Simi Valley of southern California as being defoliated by the pest in 1921. Flanders (1924) stated that the walnut spanworm completely defoliated more than 40 acres of walnut trees in 1923 in this same area.

II HOMOPTERA (APHIDS)

WALNUT APHID

The walnut aphid, *Chromaphis juglandicola* Kalt., is probably the most important insect attacking walnut. It occurs wherever walnuts are growing. According to Essig (1909) it was introduced into this country from Europe on nursery stock. Among those who early recognized it as a serious pest of walnuts were Essig (1908; 1912), Davidson (1914), Smith *et al.* (1912), and Smith *et al.* (1913) who believed that the pest was associated with the spread of walnut blight. Rudolph (1933), on the other hand, stated that the walnut aphid confines its attacks almost entirely to the leaves, which ordinarily are little affected by the disease. This was why he concluded that the aphid probably was not responsible to any great extent for the spread of bacteriosis in the nuts.

The direct damage to the tree and the developing crop may be of considerable proportions. Under extreme conditions of infestation the value of the crop may be reduced by more than 50 per cent (Michelbacher and Oatman, 1956).

DESCRIPTION

The walnut aphid (fig. 39) is a small yellow species often occurring in large numbers on the undersides of the leaves. It occurs in several forms but the individuals most frequently seen are the parthenogenetic forms which give rise to one generation after another during the growing season and into the fall until the leaves drop. These continuous-generation forms give rise to living young which tend to settle down next to the midrib of the leaflets and the lateral branches radiating from it. At birth the aphids are very small and although they can be seen by the naked eye, they are easily overlooked. In reaching the adult winged stage they cast their skins several

Fig. 39. The continuous generation form of the walnut aphid on the underside of a walnut leaflet. (× 3¼)

times. Where large populations occur, the molted skins can frequently be seen adhering to the under surface of the leaflets. The mature winged forms measure only about $\frac{1}{16}$ inch in length. They may give rise to young on the leaf on which they developed or may migrate to other leaves or even to different trees. They represent the dispersal stage.

Under conditions of high populations or in the fall, the continuous-generation forms give rise to sexual individuals. The males are tiny, somewhat smoky winged insects which are likely to escape detection unless looked for. The mature sexual females are wingless and distinguishable from other forms by two dark bands across the upper surface. Two such individuals are shown in figure 40. After mating, the females move back to the twig growth where they deposit their elongate oval eggs. The eggs are usually laid in roughened areas such as growth scars, leaf scars, and other rough places (fig. 41). When first laid, the eggs are light colored but soon turn black.

The eggs are the overwintering stage; in the spring they hatch into forms known as stem-mothers. The young of these are distinct from other individuals, and develop into parthenogenetic winged aphids that give rise to the continuous-generation forms. They are capable of flight and, like their progeny, may serve in the dispersal of the species. The most complete descriptions of the aphid and its various types of individuals, are those given by Davidson (1914).

SEASONAL LIFE HISTORY

The aphid has many generations each year. The number depends upon several factors including weather, climate, and walnut variety. Development is more rapid under warm than under cool conditions. More generations are passed on early than on late varieties of walnuts.

The winter is passed in the egg stage. The eggs begin to hatch into stem-mothers at the time the earliest varieties begin to push leaf buds. Davidson (1914), who conducted most of his life-history studies on the aphid at San Jose, observed the stem-mothers hatching from the eggs as early as February 15. This is well in advance of the time the buds start to grow. Davidson stated that these early individuals can be seen wandering over the bare twigs and buds, apparently feeding a little upon the scales protecting the unopened buds, but not showing much growth until the buds open and offer a plentiful source of nourishment. He believed that many of the early hatch-

Fig. 40. Walnut aphids on underside of a leaflet. The two individuals with dark bands are the wingless sexual females that lay the overwintering eggs. (× 4)

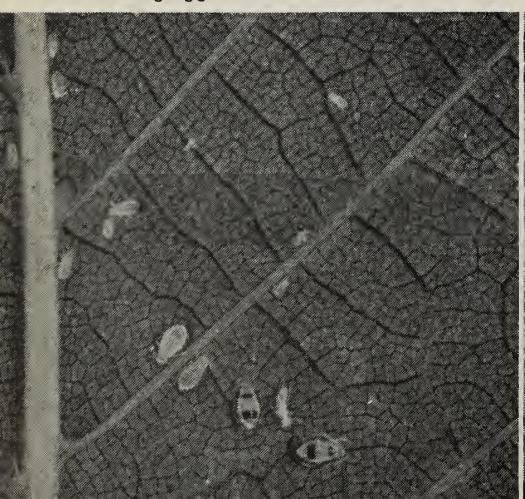


Fig. 41. Overwintering eggs of the walnut aphid laid in a leaf scar. (× 10)

ing aphids die from poor nourishment. Those surviving take six to seven weeks to complete their development, while the ones that hatch after the buds begin to push attain their full growth in five weeks. As soon as the leaflets appear, the stem-mothers move to them and settle on their under surface. Upon reaching maturity the stem-mothers give birth to the continuous-generation individuals. Davidson (1914) reported that the average number of individuals deposited by the stem-mothers ranged between 25 and 35. The length of time necessary for the continuous-generation form to complete a life cycle depends upon a number of factors including temperature, vigor of host, locality, and season of the year. In the coastal regions of northern California, Davidson (1914) found 10 to 11 generations on the early varieties and 8 or 9 on the later varieties, such as Franquette. The influence of locality, which probably reflects differences of temperature, upon the rate of development is shown in the investigations conducted by Tylor (1915) at Whittier and by Davidson (1914) at San Jose. During July at Whittier most individuals completed their development in 12 days as compared with 16 days for San Jose.

The seasonal abundance is dependent upon many factors which include physical, biological, and cultural practices, and the general influence exerted by insecticides. Where conditions are favorable to the aphid, populations may develop to a point where the undersides of the leaves may be nearly covered with the pest and quantities of honeydew excreted in amounts sufficient to make the trees look as though they had been sprayed with a syrup solution. Large populations may make their appearance at any time during the growing season. Marked variations in the abundance of the aphid from season to season may occur and this behavior has been observed on a number of occasions. Among the early investigators who called attention to this situation were Smith *et al.* (1912) and Tylor (1915). During the same year the aphid population may differ widely between areas. This was markedly demonstrated in northern California in the spring of 1956. In the interior valleys the early aphid population was the largest encountered since the walnut insect investigations were begun in that area. Yet in the coastal regions the early aphid infestation was of little concern.

The aphid is ever present and although violent fluctuations occur in the population they can be found from early spring until the leaves drop with the approach of winter. Figure 42, which has been taken from Michelbacher *et al.* (1950*b*), shows the seasonal aphid population trend occurring in 1947 in an untreated Payne orchard near Gridley in the Sacramento Valley. The graph illustrates very well the wide fluctuations that take place in the aphid population. However, it does not represent the situation occurring each year, for the aphid population trend is influenced by many factors, and investigations indicate that the population behavior is possibly never the same in any two years. Sometimes there may be but a single peak and often there is a third one; and frequently large populations are encountered in the fall.

Heavy populations stimulate the production of sexual forms, which may be found by early summer. Fall conditions also favor their production, and late in the season the winged sexual males and the wingless females may be encountered in large numbers. The females lay the overwintering eggs which can be found in increasing numbers as the season draws to a close.

DESTRUCTIVENESS

The walnut aphid is probably the most persistent insect a walnut grower has to deal with. The pest injures walnuts by inserting its stylet-like mouth parts into the leaf tissue and sucking up the plant

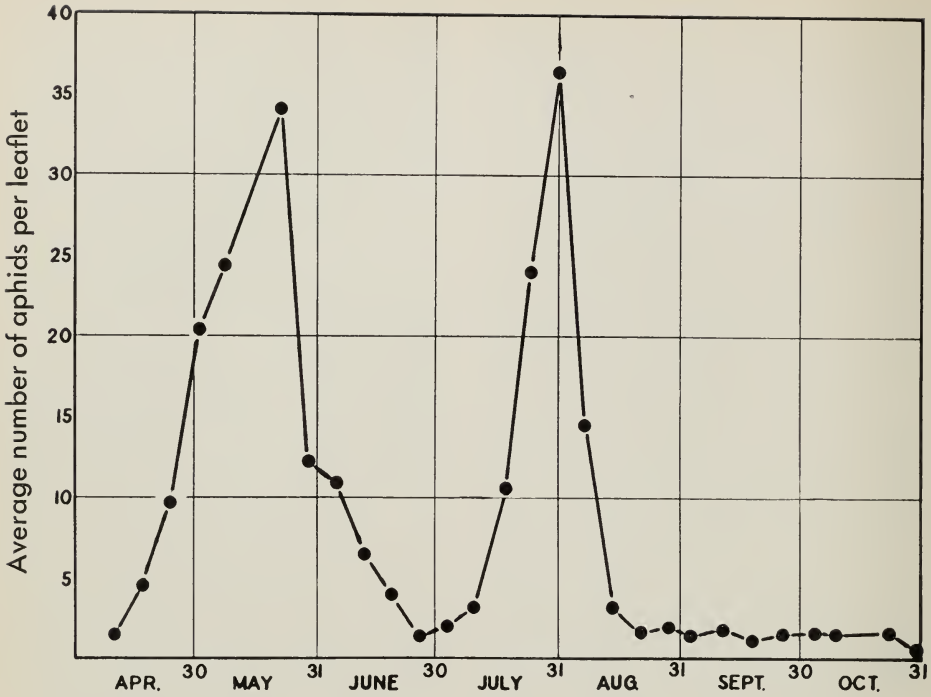


Fig. 42. Seasonal aphid population trend in an untreated walnut orchard at Gridley. (After Michelbacher et al., 1950b.)

juices. This tends to stunt the leaves and reduce the vigor of the tree. Although not proved, the aphid is also believed to inject a toxic substance into the leaf tissue while feeding. Under conditions of high populations, the quality of the nuts is impaired; there may be a premature dropping of the leaves, which exposes the nuts to sunburn and greatly interferes with harvesting operations. Further, serious defoliation early in the season may stimulate a large amount of new growth which does not have time to harden off and is subject to winter kill. A reduction in the size of the walnuts results when a severe infestation occurs during the growth period. Besides direct injury, additional damage is also done. The aphids excrete quantities of honeydew which, under conditions of heavy attack, cover the upper surface of the leaves and the outer exposed areas of the developing nuts. A black sooty mold fungus grows on the honeydew and the dark surface thus produced encourages sunburning.

The amount of damage done varies from year to year. In some areas injury of different intensity may occur each year, while in other places there may be times when little damage is done. This or similar situations have been observed by the present authors as well as by others, including Smith *et al.* (1912), Tylor (1915), and Batchelor (1924).

Besides reducing the size and quality of the crop, numerous authors have associated severe infestations of the aphid with an increase in the percentage of nuts with perforated shells. Among workers who have noted or suspected this are Smith *et al.* (1912), Smith *et al.* (1913), Tylor (1915), Batchelor (1924), and Batchelor *et al.* (1945).

With the advent of the newer systemic aphicides, an opportunity was afforded

to investigate the full effect of the walnut aphid upon the trees and the resulting crop. This has been particularly true of the systemic aphicide OMPA. A single application of this aphicide has resulted in excellent aphid control for an entire year (Michelbacher, 1954*b*, 1955*b*; Michelbacher and Oatman, 1955, 1956; and Ortega, 1956). OMPA has been used on the same plots for periods as long as three years. The plots so treated have remained almost entirely free of aphids, and the trees show a great deal more vigor than trees suffering from aphid attack. At Linden it was possible to study the effect of early-season aphids upon trees of the Payne variety and the quality of the nuts produced. The early-season aphid population was unusually large in both 1955 and 1956. Extremely high populations were encountered during the period the trees were leafing out. In 1955, where control of the aphid population was delayed until the codling moth spray was applied on May 11, the leaves were greatly stunted and less thrifty than were those from the OMPA plots. In many cases the leaflets showed tip burn, which resulted from the honeydew collected at the tips. The difference in the thriftiness of the leaves is clearly shown in figure 43. The twig growth was also more vigorous on the OMPA-treated trees.

A marked difference in the size of the nuts at harvest could be detected when nuts from the OMPA-treated trees were compared with those obtained from grower-sprayed trees which received inadequate control. The difference is illustrated in figure 44. Practically all the nuts from the grower-treated trees graded out as babies and the average weight of meats per 100 nuts was 305 grams as compared with 515 grams for the OMPA treatments. In both cases the soundness and color of the meats were good. Results obtained in 1956 substantiated those of 1955. It is certain that severe aphid infestation during leaf formation on early varieties greatly reduces the size of the leaves and the vigor of the twigs which, in turn, stunt the developing nuts to a marked degree. Among investigators who have associated aphids with reduction in size of nuts are Smith *et al.* (1913), Davidson (1914), Tylor (1915), and Batchelor (1924). Davidson (1914) observed as many as 30 aphids on a single nut; he said that nuts badly infested while young never attain normal size. While this may be so, it is believed that most reduction in nut size is caused by the feeding of aphids on the leaves, which stunts leaf, nut, and twig growth.

As yet, a severe aphid infestation has not been shown to have any great influence on the size of the crop set. However, the effect of a severe infestation has been shown to carry over into the second year. In 1955 certain plots were treated with OMPA on May 12, after the foliage had been severely injured by aphids. These plots were again treated with OMPA in 1956 before aphids had an opportunity to increase in numbers. Despite the fact that these trees were practically free of aphids after May 12, 1955, they did not appear to be quite as vigorous as those trees which had been protected with OMPA for three years.

Apparently early aphid infestations are not as destructive to late varieties as they are to early ones. Some experimental results support this contention. In the first place, a high mortality of the stem-mothers that hatch from the overwintering eggs appears to occur. Most of the eggs are believed to hatch before the buds of the late varieties are sufficiently advanced to furnish ample food for the young aphids. As a result, many of them die and a major portion of the infestation seems to arise from aphids migrating to the trees. As a result, a serious infestation does not develop until after leaf growth is well advanced. In order to determine the effect of early-season aphids upon a late variety, a block of

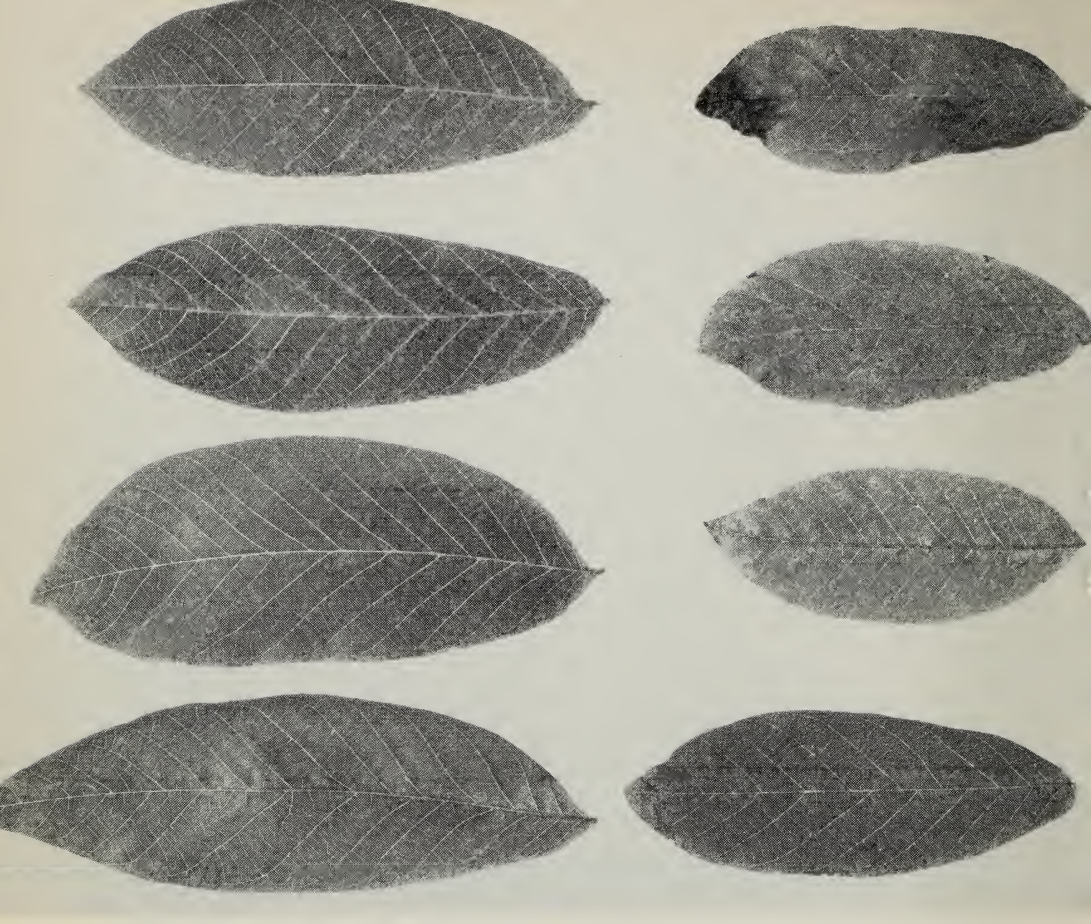
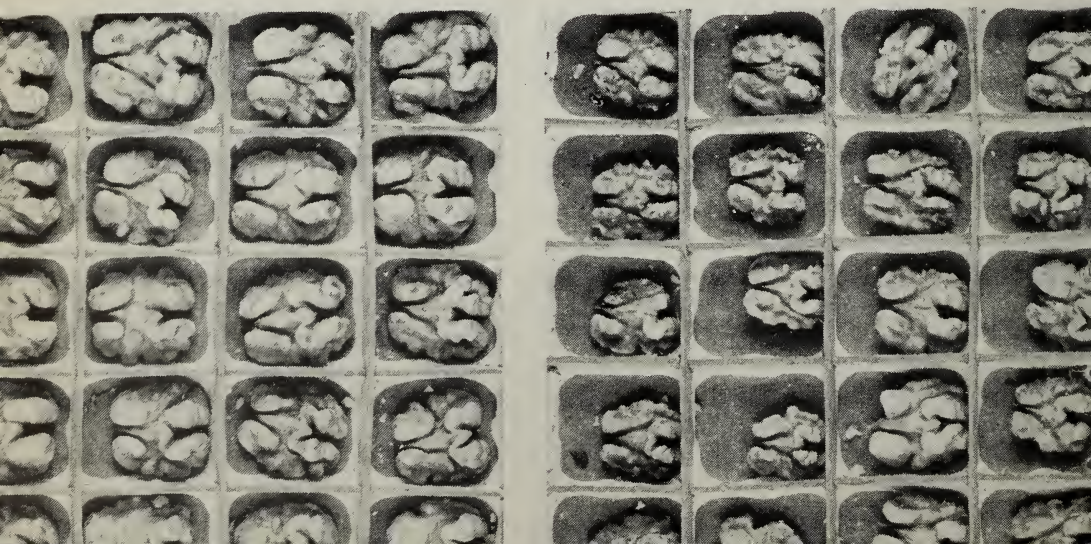


Fig. 43. Left row represents leaflets taken from OMPA plots where no aphid population developed, while those in right row were taken from plots where a large aphid population developed before the insect was controlled at time codling moth spray was applied.

Fig. 44. Left: Walnut meats from OMPA-treated plots where no aphids were present. Right: Walnut meats from grower-treated portion of orchard where aphid control was inadequate.



Franquette trees at Linden was sprayed with OMPA on May 16, 1955, just when the developing nuts were in the feather stage. Following treatment not a single aphid was found in this plot in 10 surveys conducted from May 24 to September 21. In an adjacent plot a severe aphid population developed. By June 16, the average number of aphids on the next to terminal leaflet was 67. The trees became covered with honeydew and were blackened with the sooty mold fungus. At harvest a sample of nuts was taken from each of the treatments. The weight of meats per 100 nuts from the OMPA plot averaged 462 grams as compared with 431 grams for the check plot. Although the quality favored the aphid-free plot, the difference between the treated and untreated was not marked as it is with the early varieties.

So far the discussion on aphid damage has been largely confined to the effect of the pest on walnuts in early season. The amount of injury caused by aphids in late season is somewhat more difficult to detect. It is known for a certainty that the most satisfactory crop will be obtained from trees that maintain their foliage to the normal period in late fall. Aphids are only one of the factors involved in reducing the vigor of the trees, which in turn affects the quality of the nuts both in color and soundness. Important among the others are climate, weather conditions, cultural care, other insects, and spider mites. These all form a complex and their relation to one another has been discussed in part by Michelbacher (1955*b*). Any one of them can adversely affect quality of the nuts, and disastrous results occur where several of them operate together. For instance, high temperatures, dryness, and severe aphid infestation, or severe spider mite and aphid infestations in conjunction with poor fertility and dryness can result in an almost complete loss of crop. Because these factors operate together, it is frequently difficult to assess the exact role played by each. It is certain that the loss occasioned by any one of them is greatly increased when it occurs in combination with any of the others.

In the interior valleys in 1954 and 1955, 20 per cent of the Payne crop was estimated destroyed by high temperatures and sunburn in plots that were almost completely free of aphids. In the San Jose area unusually high temperatures in early September of 1955 adversely affected quality and caused excessive losses particularly in orchards where serious defoliation had been caused by other factors. As important as aphid control is, other practices that influence quality should not be neglected. Greatest benefit is dependent upon all-round good farming.

CONTROL

Although the walnut aphid is highly destructive, the trees can tolerate a certain level of population. Apparently the early varieties are more subject to serious injury than are the later ones. The time for aphid control is dependent upon several factors. These include the abundance of natural enemies, the pest-control program followed, and the level of aphid infestation. In early season it is questionable, even with the more susceptible varieties, that treatment need be applied before the aphid population on the next to the terminal leaflet reaches 15 to 20 individuals. It is important, however, that any insecticidal program followed will insure control so complete that the aphid population is all but eliminated from the orchard.

Control of the walnut aphid can be considered under two major headings: (1) natural control, and (2) artificial control.

Natural Control

Natural control can be divided into physical and biological factors. Physical include temperature, wind, rain, exposure, and other factors that have to do with weather and climate. These can

exert a marked influence upon the walnut aphid, and often times it is difficult to appraise the exact part they play in regulating the population. Often times summer temperatures are credited with reducing the aphid population when actually the aphids were controlled by natural enemies. However, in the hot interior valleys temperatures do reach lethal levels that sometimes nearly eliminate the aphid population. Others that have observed the adverse effect of high temperatures upon the aphid include Smith *et al.* (1912), Batchelor (1924), and Michelbacher (1955*b*). Moisture conditions in an orchard regulate to some degree the lethal effect of high temperature. Mortality may approach 100 per cent in an orchard that is ready to be irrigated, while no kill may be detected in a nearby orchard which has recently been watered or is being irrigated. Although it is an established fact that aphids can be killed by hot summer temperatures, the control obtained is not without cost, for the same temperatures result in a considerable loss of crop from sunburn.

Biological factors which include predators, parasites, and diseases are extremely important in the control of the walnut aphid. Under some conditions they hold the pest under satisfactory control. If it were not for the natural enemies, control of the walnut aphid would be made much more difficult. In fact, these beneficial agencies are so efficient that control of the aphid should be left to them unless a grower is in a position to do an excellent job of destroying the aphids with insecticides. Treatment with insecticides should not be made unless they are applied in a manner that all but eliminates the pest from the orchard. Inadequate measures will result in more damage than had nothing been done. Treatments that are more destructive against natural enemies than against the aphid can only result in serious trouble.

The most important predators of the walnut aphid are ladybird beetles, syrphid flies, and lacewings. Of the ladybird beetles, the ashy-gray ladybird, *Olla abdominalis* (Say), and the convergent ladybird, *Hippodamia convergens* Guerin, are extremely important. Others of lesser value are *Adalia melanopleura* Lec., *A. bipunctata* Lec., *A. annectans* Cr., *A. frigida humeralis* Say, and *Stethorus picipes* Casey. Frequently the predators reduce the aphid population to very low levels in a few days. The walnut aphid is also attacked by at least one hymenopterous parasite, and it is sometimes infected by a fungus disease. Where control of the walnut aphid is left to natural factors, some damage by the pest may occur. Usually during the season the aphid population may reach a peak from one to three times. On these occasions much honeydew may be produced and considerable sooty mold fungus is likely to be present. The natural enemies, however, finally gain the upper hand thus producing the type of seasonal aphid population trend that is illustrated in figure 42. The value of natural enemies in reducing the aphid population was recognized by a number of early investigators, including Essig (1912) and Davidson (1914).

Artificial Control

Insecticides are widely used to control walnut pests. Many of these are ineffective against the walnut aphid, and some materials used in the walnut pest-control program actually tend to induce increases in the aphid population. Copper sprays applied to control walnut blight tend to do this. DDT, which is used primarily to control the codling moth, induces increases in the aphid population. This action has been observed on a number of occasions, Michelbacher (1955*b*), Michelbacher and Bacon (1953), Michelbacher *et al.* (1950*b*), and Michelbacher *et al.* (1945). This occurs in spite of the fact that DDT is some-

what effective in killing the aphid. However, where DDT is used in the walnut pest-control program, an effective aphicide should be incorporated with it to insure control of the walnut aphid. Frequently an aphicide is incorporated with copper sprays directed against walnut blight. Where this is done, care is exercised to select an aphicide that is compatible with copper. One such material is benzene hexachloride (BHC).

With the advent of the systemic aphicides, recommendations for aphid control are undergoing modifications. The most effective of the systemic aphicides is OMPA. The future of this material is in question, however, for at the present time it has not been nationally registered by the United States Department of Agriculture for use on walnuts, nor has a tolerance been established by the Food and Drug Administration. The second systemic aphicide is Systox. This material has proved to be highly effective against the walnut aphid, but because it can cause foliage injury (Michelbacher and Bacon (1953*b*)) it should not be applied until the trees come into full leaf. Further, it does not appear to check the frosted scale which has become a problem where Systox has been used in combination with DDT.

Other aphicides which have given good control of the aphid are parathion, malathion, BHC, TEPP, and nicotine. In the San Jose region a strain of aphid resistant to the nonsystemic phosphate insecticides has made its appearance. This alarming situation is reported upon by Michelbacher *et al.* (1954), and figure 45, which indicates a sevenfold resistance to parathion by the San Jose strain of aphid was taken from that paper. In order to delay the selecting of resistant strains, two altogether different types of aphicides, such as phosphate and a nonphosphate insecticide should be used alternately in the aphid-control program.

The importance of thorough coverage where aphicides are used cannot be overemphasized. This is necessary if satisfactory results are to be obtained. This means that aphicides must be applied with equipment that has sufficient capacity to reach the tops of the trees, or otherwise insure thorough coverage. Where air-carrier sprayers are employed, the aphicide should be applied in from 50 to 200 gallons of water per acre depending upon the capacity of the equipment. For best results applications should be made at a time when there is little air movement. Dusts or concentrated sprays can be applied by aircraft if sufficient care is used and if favorable weather conditions exist.

Under normal conditions satisfactory control of the aphid for the entire season should be obtained with one to three treatments. Control with a single application is possible where systemic aphicides are used or where the aphid does not present a serious problem.

There is no question but what the aphid problem would be less severe if all growers in a given locality would apply effective treatments in a well-coördinated

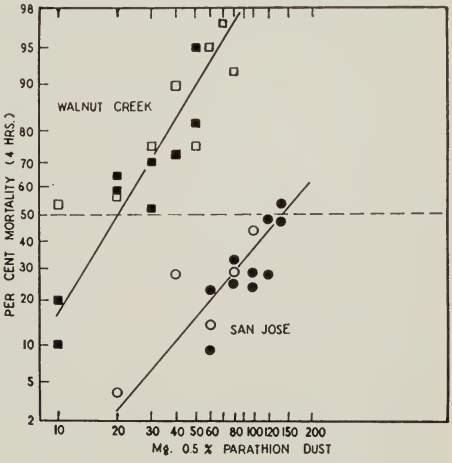


Fig. 45. Log probit mortality curve for nonresistant Walnut Creek strain of the walnut aphid as compared with that of the resistant San Jose strain. Open squares and circles, tests run August 14, 1953; and solid squares and circles, tests run August 21, 1953.

program. Heavily infested orchards increase the problem of aphid control in nearby groves. This is particularly true if effectively treated orchards are to the leeward side. Migration of winged aphids from heavily infested orchards can be of considerable proportions. Some measure of the importance of migrating aphids was obtained in the experimental orchard at Linden during 1951 and 1952. The outer five to ten rows in both years became heavily infested in from four to five weeks after treatment, while the trees deeper in the orchard remained almost free of aphids. The difference encountered is graphically shown in figure 46 which has been taken from Michelbacher and Bacon (1953*a*). It should be pointed out that the problem of migrating aphids is greatly reduced where systemic aphicides are employed.

DUSKY-VEINED WALNUT APHID

The dusky-veined walnut aphid, *Panaphis juglandis* (Kaltenbach), is a rather recently introduced pest of walnut in California (Michelbacher, 1954*a*). It was first observed in 1952 in the San Jose area. At that time some orchards were rather heavily infested. Since then the pest has been found widely distributed over many of the walnut-producing areas adjacent to the San Francisco Bay. It has also spread into the Salinas Valley.

The dusky-veined aphid, which is probably a European species, occurs in both California and Oregon. Thompson (1929) observed it for the first time in the United States in the Willamette Valley of Oregon in 1928, where its damage was affecting between 2,000 and 3,000 acres of walnuts.

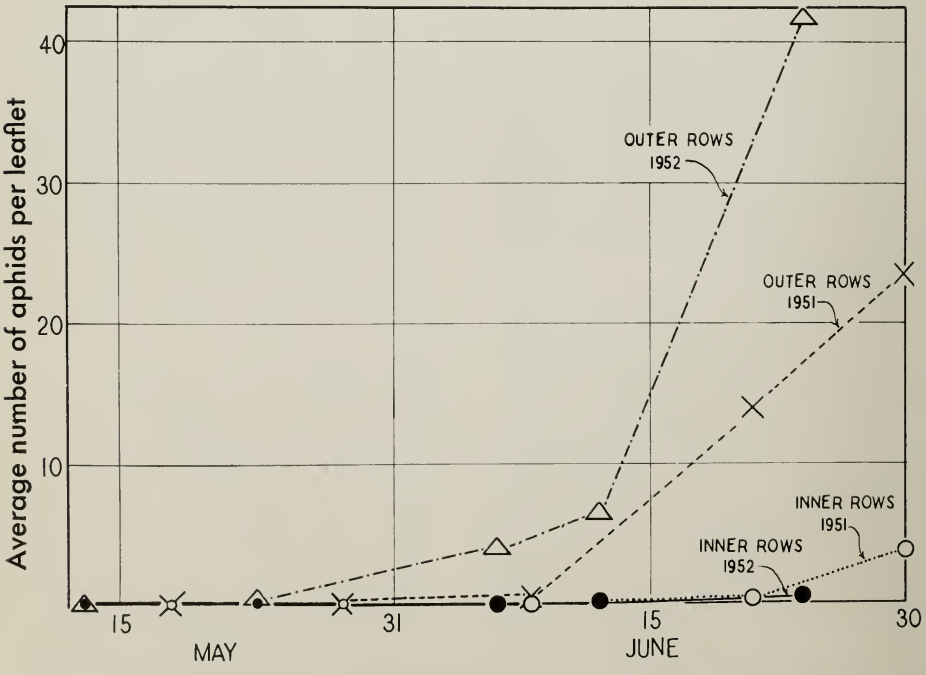


Fig. 46. Influence of migrating aphids on the pattern of reinfestation in the experimental orchard at Linden, 1951 and 1952.

DESCRIPTION

The dusky-veined walnut aphid (fig. 47) is much larger than the common walnut aphid. Further, it occurs on the upper surface of walnut leaflets in contrast to the ordinary aphid which lives on the lower surface. The dusky-veined walnut aphid develops in very characteristic colonies with the individuals lining up in a uniform manner on either side of the midrib of the leaflets.

SEASONAL LIFE HISTORY

To the present time no opportunity has been afforded to study this aphid under California conditions. During the growing season it has numerous generations. Its seasonal behavior is probably similar to that of the aphid which occurs in Europe, and the following seasonal cycle has been adapted from the investigations of Poljugan (1930) who conducted his studies in northern Yugoslavia. The winter is spent in the egg stage. In the spring these hatch into stem-mothers which give rise to alate viviparous parthenogenetic females, which produce successive generations into the fall. As the end of the growing season approaches, alate males and apterous females make their appearance. These mate and the females lay the overwintering eggs in small cracks in the trunk bark of the trees. The seasonal life cycle is very similar to that of the common walnut aphid.

DESTRUCTIVENESS

Thompson (1929), who conducted his studies in Oregon, observed that the midribs of infested leaflets are blackened and shriveled. He stated further that the leaves had a sickly appearance and were blotched with yellow. Poljugan (1930) reported somewhat similar injury occurring in Yugoslavia.

Not enough observations have been made in the infested regions of California to know exactly how much damage the pest might do. From what little has been seen it appears that serious infestations can be expected to reduce the vigor of the trees. So far the pest has

Fig. 47. The dusky-veined walnut aphid. This species is much larger than the common walnut aphid and occurs on the upper surface of the leaflets. (× 2; photo courtesy Jack Dibble.)

not presented a serious problem, probably because treatments directed against the common walnut aphid have held the dusky-veined aphid under suppression.

CONTROL

As with other aphids, natural control is important in limiting populations of the dusky-veined walnut aphid. Because it develops on the upper surface of the leaflets, it is more easily contacted with aphicides than are most species of aphids which usually live on the undersides of leaves and are thus better protected from treatments. To the present time no control studies have been directed against the pest. In recent years its occurrence has been spotty, and the available evidence indicates that the reason for its scarcity is the fact that it is held in check by treatments directed against the common walnut aphid.

III HOMOPTERA (SCALE INSECTS)

A number of scale insects attack walnuts. While most are of minor importance, several inflict serious and widespread damage. Both unarmored and armored species are involved.

UNARMORED SCALES

In general, unarmored scales are larger than armored scales and do not form a shell over the body as do the latter. Further, they secrete quantities of honeydew, while little if any is produced by armored scales. The taxonomy of soft scales is in need of extensive investigation, but in the complex that infests walnuts at least three important species are involved.

FROSTED SCALE, *LECANIUM PRUINOSUM* COQUILLETT

The frosted scale on walnuts has a long history. At the time Coquillett (1891) described the species in 1891, he listed walnut as one of the hosts. However, until recent years it has not been considered a serious pest of walnuts. As early as 1913, Essig (1913) stated that because of parasites the frosted scale scarcely does any damage. Coquillett (1892), it is also interesting to note, observed that it was attacked by a small chalcid fly. However, since the advent of DDT, the frosted scale has become a serious pest, a condition believed to be caused largely by the fact that DDT and others of the newer insecticides have interfered with effective parasitism of the pest. (Bartlett and Ortega, 1952; Michelbacher and Bacon, 1952; Michelbacher and Middlekauff, 1949; Michelbacher *et al.*, 1946; Michelbacher and Hitchcock, 1956; Michelbacher, 1955*a*, 1956*c;* Middlekauff *et al.*, 1947; and Ortega, 1953*b*).

DESCRIPTION

The young of the frosted scale (fig. 48) are tiny, flattened, oval, elongate yellowish insects which, on the underside of walnut leaves, may be mistaken for very young nymphs of the walnut aphid. By fall (fig. 49) the color changes to dark amber or brown and a scattering of fine waxy filaments may protrude from the base of the bodies. In the spring, as growth rapidly begins, the bodies become distinctly convex in shape and are covered with a dense frost-like wax (fig. 50, left). With maturity, the frost-like wax covering tends to weather away, leaving the scales as shown in figure 51. At this time they are rich brown to blackish brown in color and measure about ¼ inch in diameter. The bodies are strongly convex, somewhat oval, smooth and full of tiny eggs which are oval and creamy or light tan in color at

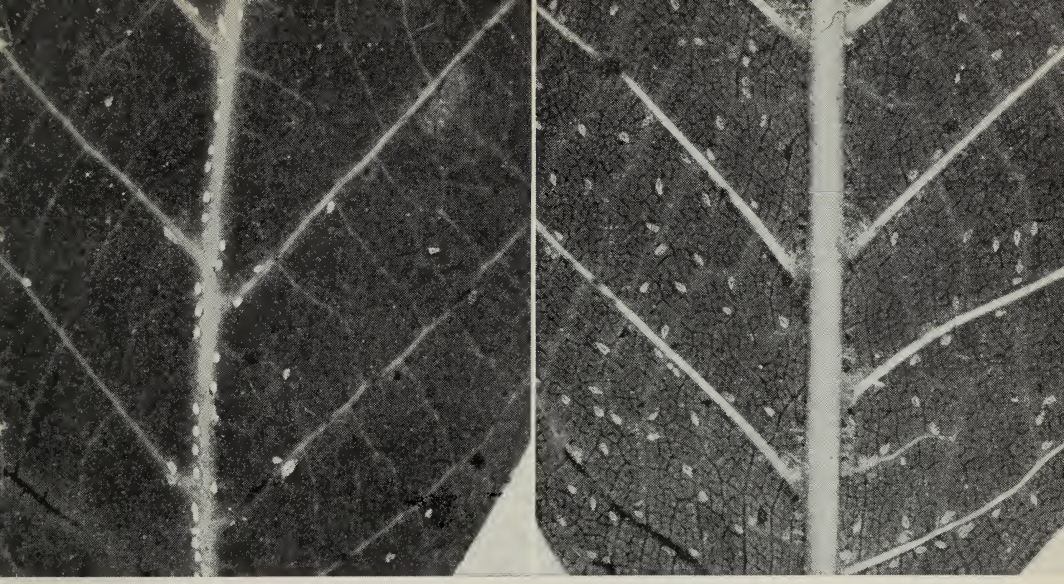


Fig. 48. Tiny young of the frosted scale. Left: As they appear on the upper surface of a leaf. Scattered larger specimens are those of the calico scale. Right: Same for lower surface of leaf. (× 3½)

first, but which turn brownish when about ready to hatch. The eggs hatch into tannish crawlers, with well-developed legs. The parent scale dies and remains on the twigs until it weathers off.

SEASONAL LIFE HISTORY

The frosted scale has but one generation each year. Eggs of the scale, which remain under the parent, hatch during the last half of May, through June, and in some localities probably into July. The crawlers leave the mother scale and migrate to the leaves, leaf petioles, and current season's twig growth. Here the insects settle mostly on the lower surfaces. Development is slow and although some growth occurs, the elongate flattened scales remain extremely small throughout summer, fall, and into winter. With the approach of winter the scales molt. Individuals that settled on the leaves tend to move back to twig growth before the leaves fall. Beginning in late winter, another molt occurs, and development of the scales is accelerated to a rapid point through early spring. During this period the scales become covered with a powdery white wax; quantities of honeydew are secreted. From the time the scales first settle down they produce honeydew, but because of their tiny size the amount secreted is small and goes unnoticed unless the scales are present in great numbers. With large populations, the foliage may appear as though atomized by the honeydew; as a result, the walnut aphid often is blamed for its presence.

Eggs are produced during April and May and, as energy is expended on egg production, less and less honeydew is secreted. An enormous number of eggs are laid, which occupy the entire space beneath the scale. With egg production completed, the scales die and the waxy covering weathers away.

Other hosts besides walnut include apple, apricot, cherry, peach, pear, and plum. Walnut appears to be one of the preferred hosts.

DESTRUCTIVENESS

The full impact of this scale upon walnut trees is not entirely known. It is believed that a moderate population can be tolerated. However, serious damage ap-

Fig. 49. Stage of development of the frosted scale in early November. (× 6)

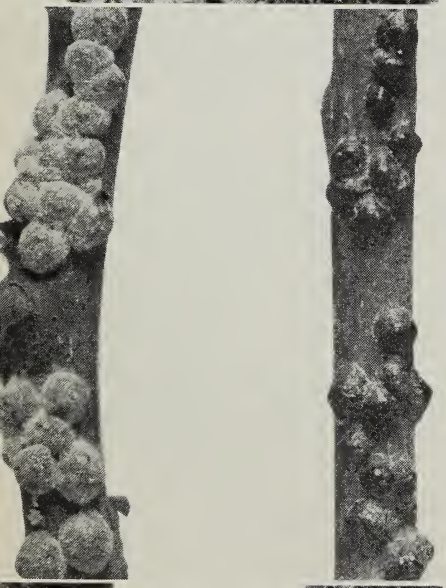


Fig. 50. Left: Frosted scales with maximum covering of frost-like wax. Right: Specimens of the European fruit lecanium, a soft scale which can be confused with the frosted scale. (× 1½)

Fig. 51. Mature frosted scales. The frost-like wax covering is beginning to weather away. (× 2¼)

pears to occur when the scale population reaches a point where it cakes the twig growth. Under these conditions the vigor of the trees is impaired. Injury results from the quantities of cell sap extracted from the trees, and from the large amounts of honeydew excreted by the scales. The reduction in the vigor of the trees is reflected in a lowering of the size and quality of the nut crop.

CONTROL

Control of the frosted scale is principally obtained through natural agencies or through the application of insecticides.

Natural Control

Of the natural factors, parasites appear to be by far the most important. The frosted scale seldom becomes a problem where the action of these natural enemies is not interfered with. DDT and some of the other new insecticides have exerted an adverse effect upon the natural enemies, reaching such serious proportions that at the present time the frosted scale ranks as a major pest of walnuts. Not only has the problem been aggravated through the use of DDT in the orchards to control the codling moth and other pests, but by the drift of DDT through orchards when adjacent crops are dusted at critical periods. It is also believed there may be a regional effect from the drift of insecticidal dusts where these are used in abundance to control pests on other crops over a wide area. The increase in the scale population following insecticidal dust drift through an orchard may be of devastating proportions.

It can safely be said that within a walnut orchard any insecticide not effectively checking the frosted scale but adversely influencing its parasites is very likely to result in a serious increase in the scale population.

Investigations have shown that the adverse action of DDT becomes more apparent with an increase in the amount of DDT applied per acre in the May codling moth spray. A sharp rise in the scale population is likely to occur where the amount of DDT 50 per cent wettable powder is used at a rate in excess of eight pounds per acre, although lighter dosages tend to induce an increase in the population. At the time the May spray is applied, the scales have reached maturity and are full of eggs. The parasites are also completing their development within the scales, but the bodies of the scales protect them from contact with the spray. Apparently, then, when low dosages of DDT are employed, the residual action of the spray, insofar as the parasites are concerned, has lost much of its toxicity by the time the parasites emerge from the scales in late May and June. However, where larger amounts are applied, the spray residue is highly toxic to the parasites at the time they issue from the host.

A number of parasites attack the frosted scale. These include *Encyrtus californicus* (Girault), *Coccophagus lycimnia* (Walker), and *Metaphycus californicus* (Howard). Of the above, *Metaphycus californicus* (Howard) is the most abundant and important species. This parasite has several generations each year, while the frosted scale has but one. The situation allows for a rather rapid increase in the parasite population, and its repeated opportunity to parasitize the scale favors excellent biological control.

An interesting seasonal relation exists between the parasite and its host. During the summer and fall the parasite multiplies in the small young frosted scales. In the dormant season, development and multiplication of the parasite come to a standstill, but in the late winter and early spring they begin again. During this period (summer, fall, and late winter) an individual scale furnishes only sufficient food for the development of a single parasite. A scale parasitized during this period appears somewhat mum-

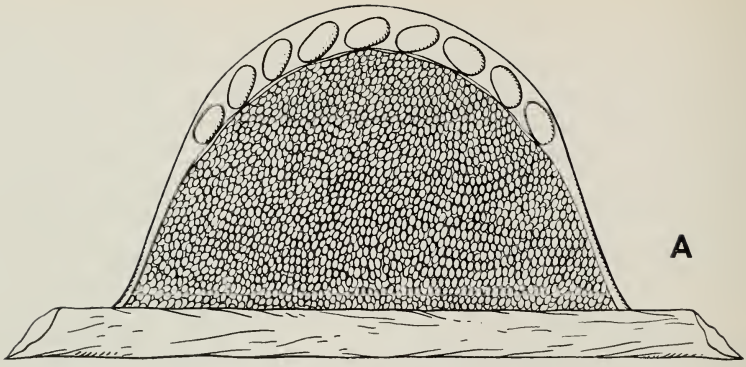


Fig. 52. (A) Diagrammatic cross section of a parasitized scale on a twig showing entire space beneath the scale filled with minute eggs, and larger developing parasites in dissipated body of scale. (B) Ventral view of scale as in sketch with eggs removed. (C) Same as above with dry skin broken away revealing the developing parasites. (× 8) (After Michelbacher, 1955a.)

mified, and is characteristically humped, which serves at a glance to distinguish it from the flattened, normal, nonparasitized individuals. However, once the host enters the period of rapid development, it can support more than a single parasite, and parasitism does not appear to interfere with its normal growth. Eggs are produced in quantity, and there are no easily detectable external signs of parasitism. If, on reaching maturity, a parasitized scale is turned over, eggs pour out in enormous numbers. In spite of the large number of eggs produced, an individual scale may, and usually does, contain upward of 12 or more parasites. A parasitized scale could easily escape detection for, with the eggs removed, the scale appears to be empty. It might be compared with a helmet that has an inner lining.

The situation that exists is illustrated in figure 52. Figure 52*A* is a diagrammatic sketch of a parasitized scale on a twig, showing how the entire space beneath the scale is filled with an extremely large number of eggs. Above the mass of eggs is the thin, dried, almost parchment-like skin of the scale, and between the skin and the outer wall of the scale are numerous parasites. Figure 52B is a photograph of a scale with the eggs removed, and figure 52C shows the dry skin broken away, revealing the developing parasites. After the parasites have completed their development, they leave

the host. A parasitized scale can be detected by the numerous tiny circular emergence holes. Where a massive scale population has been allowed to develop, parasites will reduce it to a nondestructive level in about a year if the practices responsible for parasite destruction are discontinued. Frequently, during the later stages of the cycle, a grower who is unaware that the scales are heavily parasitized believes that the orchard is certain to be seriously infested. The degree of parasitism of old scales frequently ranges between 90 and 100 per cent. Parasitism in this range is sufficiently great in most cases to check the frosted scale population. Figure 53 shows the parasite host relation that existed on May 3, 1953, in a severely infested orchard where the frosted scale was about to be reduced to a nondestructive level by natural enemies.

Not all insecticide-induced increases in the frosted scale population may be due to the adverse action of the insecticide upon natural enemies. Increases have occurred which may not be associated with an interference with natural enemies. It is possible that some insecticides such as those having a systemic action might induce an increase in the scale population through some physiological stimulation.

Whatever the causes, the seriousness of insecticide-induced increases in the scale population presents a real problem, and one that is in need of further extensive investigation.

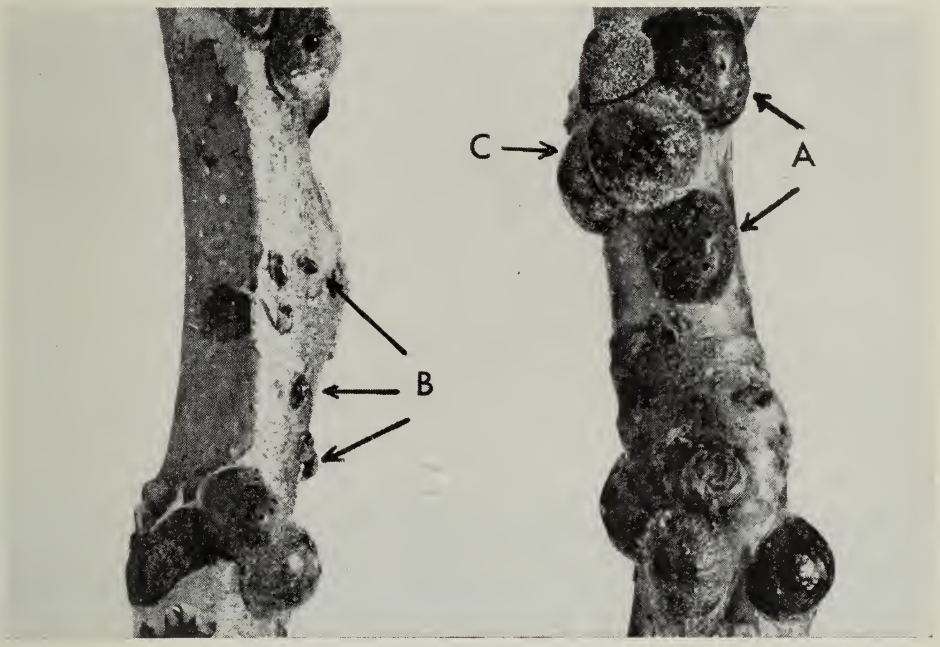


Fig. 53. Condition of a severe frosted scale infestation on walnut, May 3, 1953, that is about to be reduced to a nondestructive level by natural enemies. (A) Scales which were parasitized by Metaphycus californicus (Howard) in late winter and early spring of 1952 and from which the parasites emerged in June, 1952. (B) Mummified bodies of scales which were parasitized in the fall of 1952 and from which the parasites have emerged. (C) Scales which escaped parasitism until at least late winter and spring of 1953. Of these, about 90 per cent are parasitized and represent a condition as shown in figure 4. (× 3) (After Michelbacher, 1955 a.)

Insecticide Control

The only period when the frosted scale cannot be controlled with insecticides is from the beginning of rapid growth in the late winter until the eggs have all hatched. This ranges, according to locality, from about the middle of February to the end of June. During the summer and winter the scale can be adequately controlled by insecticides, such as parathion and malathion. For summer control less active material is needed than for winter control. Also, in the full dormant period, dormant oil emulsions can be used in those areas where oil causes no injury.

Aphicides such as parathion and malathion used in the summer to control the walnut aphid exert a marked suppressing action upon the frosted scale. Treatments of this kind tend to mask the effect of those insecticides which induce increases in the frosted scale population.

OMPA at a pound of actual ingredient per acre has a residual suppressing action when applied early in the season or in combination with the codling moth spray for the control of the walnut aphid.

Many insecticides tend to induce increases in the scale population. This subject was covered in the section on natural control.

EUROPEAN FRUIT LECANIUM, *LECANIUM CORNI* BOUCHÉ

In many ways this scale resembles the frosted scale and may be confused with it. Its habits are the same as those of the frosted scale, and the two scales often occur together in the same orchard. The European fruit lecanium, however, is far less abundant on walnut than is the frosted scale.

DESCRIPTION

The immature stages closely resemble the young of the frosted scale. Adults (see fig. 50, right) are a shiny brown, and tend to be slightly longer than broad. They are strongly convex with a slight indication of a bilobed condition. The integument is not quite as smooth as that found in the frosted scale, and while coated with a sparse amount of frost-like wax, the quantity involved does not approach the dense covering found in the frosted scale. At maturity the space beneath the scales is full of tiny, more or less oval, tan to pinkish eggs. These hatch into yellow to pale-brown crawlers with well-developed legs.

SEASONAL LIFE HISTORY

The European fruit lecanium has only a single generation each year. Its habits parallel those of the frosted scale. The scales are likely to be found on the under surfaces of leaves and twigs. The adults may tend to reach maturity just a bit in advance of the frosted scale. In the field the only time they can be separated from the frosted scale is in late winter and spring. Unlike the frosted scale, the European fruit lecanium does not become heavily coated with the frostlike wax. The tendency toward the bilobed condition, the slightly roughened integument, along with having the body a bit longer than wide is helpful in separating the European fruit lecanium adults from those of the frosted scale.

DESTRUCTIVENESS

Because this species has been and can be confused with the frosted scale, it is not possible to give any definite information on the amount of damage it causes. It injures trees in the same way as the frosted scale; for this reason heavy infestations should not be tolerated.

CONTROL

Information on the control of this insect on walnuts is most incomplete. Natural factors are very important. In the full dormant season it can be controlled with dormant oil sprays. Aphicides such as parathion and malathion when used in the summer to control the walnut aphid tend to suppress the European fruit lecanium. At Linden a parathion spray

Fig. 54. Recently mature calico scales on walnut twigs. Later the color pattern tends to fade and the bodies shrivel to a small degree. (About actual size.)

applied on February 18, 1956, to control the frosted scale failed to kill the European fruit lecanium. However, more recent experiments have demonstrated the fact that parathion is effective against the pest if used in combination with oil. The investigations give evidence that in late winter the European fruit lecanium is more resistant to parathion than is the frosted scale.

CALICO SCALE, *LECANIUM CERASORUM* COCKERELL

The calico scale is widespread on walnuts but at the present time is not considered a serious pest of the crop. This situation occurs even though some of the newer insecticides such as DDT and OMPA tend to induce increases in the population. Hosts besides walnuts include cherry, pear, and prune as well as such ornamentals as Boston ivy and Virginia creeper.

DESCRIPTION

This is a large globular species measuring about ¼ inch in diameter. It is a shiny dark brown with a number of regular white markings on its back (fig. 54). The color pattern has given the scale its common name, calico. The color is brightest at the time the scale reaches maturity. After this it begins to fade and following death the scale tends to shrink in size. The tiny, pale-colored eggs hatch into tannish crawlers with well-developed legs. The young settle mostly on the

Fig. 55. Young of the calico scale that have settled on the leaf. (Left: Upper surface. Right: Lower surface. (× 5)

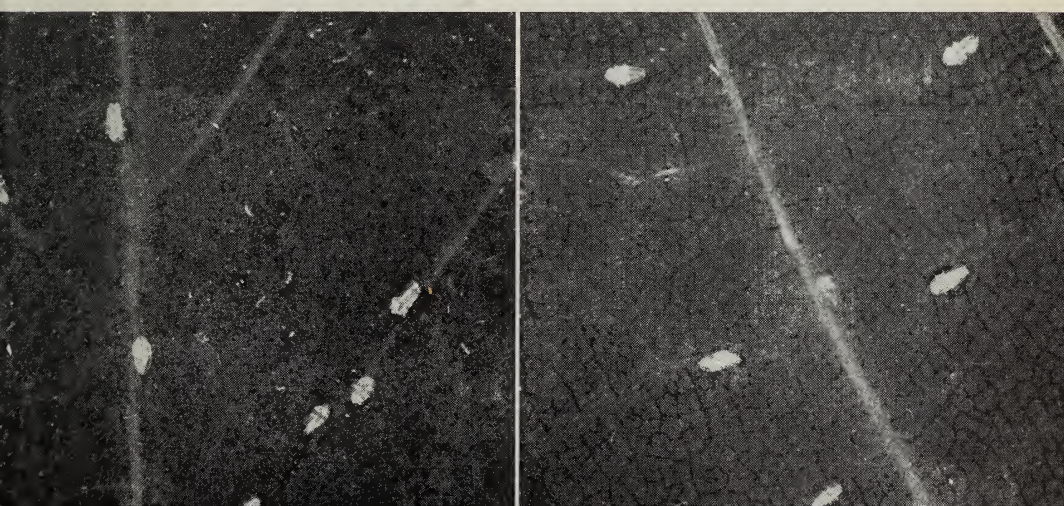


Fig. 56. Young of the calico scale as they appear in early November. (× 4½)

undersides of the leaves and twigs. The young (fig. 55) are larger and more elongate than are those of the frosted scale. In the summer and fall they can be distinguished from individuals of the frosted scale in that they are covered with a cake-like wax material which forms more or less of a pattern over the top of the scale (fig. 56). In late winter the young are covered with a waxy coat that is arranged in a definite and characteristic pattern. By this pattern they are easily distinguished from the young of the frosted scale which are smaller and without a covering at this time.

SEASONAL LIFE HISTORY

Like the other lecanium scales discussed earlier the calico scale has but one generation a year. Its seasonal development is the same as that of the frosted scale, the only important difference being a bit more rapid development. This is apparent in late winter and in the spring. Maturity is reached at an earlier date and the eggs hatch before those of the frosted scale.

DESTRUCTIVENESS

The calico scale injures trees by sucking up the cell sap and by secreting quantities of honeydew. Serr (1933) reported that in some cases the scales became so numerous they were literally piled up one on top of the other. At the present time serious infestations are seldom encountered and in recent years there has been little information in the literature concerning the calico scale as a pest of walnuts. Lockwood and Gammon (1949) reported a medium infestation of this scale in Alameda County.

CONTROL

The probable reason why the calico scale has not been a problem for many years is the fact that it is usually effectively held in check by natural enemies.

Fig. 57. Walnut twig showing whitish impressions left by young developing calico scales that were eaten by Audubon's warblers. Only a single scale escaped and it was parasitized by Blastothrix longipennis Howard, as evident by the emergence holes in the scale body. (× 3)

It appears that the most important predator of this scale is the Audubon's warbler, *Dendroica auduboni,* which during late winter and early spring destroys enormous numbers of individuals (fig. 57). Lowe (1935) established the fact that this insectivorous bird was a highly effective predator of the calico scale. It feeds on the scales during that stage when the waxy coating is arranged in a definite and characteristic pattern. Lowe (1935) made a scale count on a group of branches where the birds had been feeding and found that out of 1,093 individuals the birds destroyed all but 63, and that most of these were parasitized.

At Linden, a serious calico scale population was encountered during the winter of 1955–56. This heavy infestation was nearly eliminated by the Audubon's warbler during the late winter and early spring. The number of scales destroyed can be determined because the spot where they were attached is marked by a white outline (fig. 57). Most of the few scales that escaped the birds were parasitized by the wasp, *Blastothrix longipennis* Howard,[6] which has not yet been distinguished from *sericea* Dalm. A more complete account of the calico scale and its enemies is given by Michelbacher and Hitchcock (1956).

The control of the calico scale by natural enemies is remarkable when one considers that it is occurring under conditions where applications of insecticides tend to induce increase in the scale population.

OTHER SPECIES OF SOFT SCALES

Besides the above species, other soft scales have been taken on walnut. Essig (1914) reported the black scale, *Saissetia oleae* (Bern), as occurring in exceptional numbers on walnut in the Goleta district of Santa Barbara County. Quayle (1915) stated that the citricola scale, *Coccus pseudomagnoliarum* (Kuw.), has occurred on walnuts growing near citrus trees. The Asiatic scale, *Lecanium kunoense* Kuw., has been reported on walnut by Armitage (1945). Walnut is a host to the excrescent scale, *Lecanium excrescens* Ferris.

[6] Determined by Harold Compere, University of California Citrus Experiment Station, Riverside.

ARMORED SCALES

Several species of armored scales infest walnuts. Some of these occur over rather extensive areas and on occasions are highly destructive to the crop.

OYSTERSHELL SCALE, *LEPIDOSAPHES ULMI* (L.)

This scale is widespread; in some localities it may seriously attack walnuts. It has a very large host range and infests both cultivated and uncultivated plants. Among the plants attacked besides walnut are apple, apricot, cherry, peach, pear, poplar, and willow.

Fig. 58. A walnut twig heavily encrusted with the oystershell scale. (× 2¼)

DESCRIPTION

The adults (fig. 58) resemble tiny oystershells. It is from this likeness that the insect derived its common name. The females are larger than the somewhat oval males and are approximately 1/8 inch in length and about 1/3 as wide. The color ranges from light to dark brown. The eggs are oval and pearly white. They hatch into tiny crawlers with well-developed legs, which move to the twig growth and even to the developing nuts where they molt and settle. Following the first molt they lose all power of locomotion. The young grow rapidly. At first they are a somewhat dirty white but as they develop they take on the brown color of the adult.

SEASONAL LIFE HISTORY

On walnuts the oystershell scale appears to have but one generation a year. The eggs begin to hatch in May, possibly continuing to hatch into June in cooler climates. Soon after emerging from the eggs the crawlers move to the twigs, smaller branches, and developing nuts where they molt and settle. Growth is rapid, with maturity reached and eggs produced before winter sets in.

DESTRUCTIVENESS

The oystershell scale often occurs in extremely large numbers. They may be so abundant that they encrust the twigs and small branches. Under conditions of extreme populations they may even cover the developing nuts. They are principally bark feeders and cause injury by sucking up the plant juices. It is possible that they inject a toxic substance at the point of feeding. Destructive populations may cover an entire tree or only a single branch or limb. Sometimes only a branch here and there throughout an orchard may be infested. Where severe and heavy infestations occur the vigor of the affected portions of the trees is greatly reduced and if the infestation goes unchecked the affected part may be killed.

CONTROL

The oystershell scale is held in check either by natural agencies or by the application of artificial measures. Over most of the walnut-producing sections it is suppressed by natural factors. On occasions serious outbreaks occur which, it is believed, result from some interference with natural control. Just how the natural factors are affected is not known. Possibly the insecticides used to control the pests of walnuts have an adverse influence upon the parasites of the scale. Dust drifting through an orchard when adjacent crops are treated for pest control may have a similar effect. This phase of the problem is in need of thorough investigation, for a knowledge of the exact factors involved would certainly be helpful in developing a program that would not seriously interfere with natural control, which so effectively suppresses the scale.

Where a single branch is heavily infested it should be cut out. Where the infestation is general it can be controlled with a thorough application of parathion 25 per cent wettable powder applied at the rate of 5 pounds per acre. The timing of the treatment is critical, and the chemical should be applied as soon as the eggs have hatched and before the scales have developed beyond the dirty-white stage or white-cap stage.

ITALIAN PEAR SCALE, *EPIDIASPIS PIRICOLA* (DE GUER.)

This scale sometimes seriously infests walnut. It also attacks other crops, such as apple, peach, pear, and plum.

DESCRIPTION

The scale covering of the female is circular, light gray, shiny, and with brown exuvia slightly off center. It measures about 1/16 inch in diameter. The body of the female is dark reddish purple, which helps to distinguish it from

related species. The minute male scale is elongate, white, with the exuvia at one end.

SEASONAL LIFE HISTORY

According to Quayle (1938), the Italian pear scale on walnut is believed to have but a single generation each year. However, Essig (1920) stated that on deciduous fruit trees several generations overlap yearly.

DESTRUCTIVENESS

The Italian pear scale is a bark feeder and is restricted to the trunk and limbs. Its development is favored by moss and lichens and where these prevail the pest often develops in large numbers. In some cases the bark under the growth is literally caked with the scale. Severe populations beyond a doubt reduce the vitality of the trees by their feeding, so that the affected areas may be killed. Feeding causes depressions or deformations to form in the larger limbs. According to Essig (1920) these may eventually crack or become dead, sunken areas.

CONTROL

The Italian pear scale has a number of natural enemies that tend to hold it in check. It apparently is a pest only where moss and lichens are allowed to cover the trunks and branches. This situation can be corrected by destroying the moss and lichens during the dormant season with a thorough coverage spray containing 10 to 15 pounds of hydrated lime plus 1 gallon of oil emulsion to the 100 gallons of water.

PUTNAM SCALE, *DIASPIDIOTUS ANCYLUS* (PUTNAM)

The Putnam scale is widely distributed in California. It has a broad host range besides walnut, and attacks such crops as apple, apricot, cherry, peach, pear, plum, and numerous shade trees and ornamentals.

DESCRIPTION

The following description has been largely adapted from McKenzie (1956). The scale of the female is light to dark gray, circular, quite convex, and with the exuvia to one side. The male scale is elongate, gray, with the exuvia toward one end. A summer infestation on walnut is shown in figure 59. The species appears to be somewhat similar to the San Jose scale and can be mistaken for the latter. On the older twig growth the scale can be easily overlooked unless searched for.

SEASONAL LIFE HISTORY

The Putnam scale has at least one generation each year with some evidence of a possible second one.

DESTRUCTIVENESS

Although widespread, the Putnam scale has not been considered a serious pest of walnuts. Apparently natural enemies have played an important role in holding the population below an economic level. However, treatments with some of the newer insecticides may be responsible for inducing increases in the population. In some of the experimental plots at Linden, the scale has reached a destructive level, and twigs in places are well coated with the scale, as is shown

Fig. 59. A walnut twig heavily infested with the Putnam scale as it appeared on July 3, 1956. (× 3½)

in figure 59. Under these conditions the vigor of the tree is reduced and the affected parts may be killed. In their investigations on elms, English and Decker (1954) observed a direct correlation between the number of DDT treatments applied and the severity of the Putnam scale infestation.

CONTROL

Observations have been made which show that the Putnam scale is heavily parasitized. Apparently under most conditions natural enemies if not interfered with can be relied upon to suppress the population.

Recent investigations have shown that dormant applications of parathion in combination with oil are effective against the pest. Also, there is evidence that it is suppressed by early summer treatment of parathion directed against soft scales.

WALNUT SCALE, *QUADRASPIDIOTUS JUGLANS REGIAE* (COMSTOCK)

Besides walnut, the walnut scale infests numerous other hosts which include apple, apricot, cherry, peach, pear, and plum. The adult female is almost circular, gray, convex, and with the exuvia nearly central. The male scale is elongate oval with the exuvia near one end.

Quayle (1938) stated that it is of some importance on walnuts, although it apparently is not a serious pest in orchards receiving good care.

OTHER SPECIES OF ARMORED SCALES

Besides the armored scales already mentioned, several others infest walnuts. However, none of these appears to be a serious pest. Essig (1926) lists the San Jose scale, *Aspidiotus perniciosus* Comst., the greedy scale, *A. camelliae* Sign., and the California red scale, *Aonidiella aurantii* (Maskell), as attacking walnut. The first species appears to have become a pest in localized areas. Judging from the investigations of Lindgren and Dickson (1940) the walnut is a relatively poor host of the California red scale. However, recent findings in 1957 have shown that it can become a severe problem. Random samples taken from an orchard in Santa Barbara County showed 85 per cent of the one-year-old wood and 92 per cent of the two-year-old wood infested. Considerable dieback of the heavily infested twigs was observed.

IV WOOD BORERS (COLEOPTERA)

A number of beetles attack walnut. Most of these seek trees that have been injured or whose vigor has been reduced in one way or another. Healthy trees growing under the best cultural conditions are seldom attacked.

PACIFIC FLATHEADED BORER (Family Buprestidae)

The Pacific flatheaded borer, *Chrysobothris mali* Horn, a native species, is probably the most destructive beetle pest of walnut. It attacks a large number of forest, shade, and orchard trees and bush berries. Although walnut may be seriously attacked, it does not appear to be one of the most favorable hosts.

DESCRIPTION

The Pacific flatheaded borer has four stages in its development: adult, egg, larva, and pupa.

Adult. The adult and larvae are shown in figure 60. The adults are flattened and range in length from about $\frac{5}{16}$ to $\frac{7}{16}$ inch. The color is dark bronze or reddish

Fig. 60. The Pacific flatheaded borer. An adult and the work of the larvae on prune. (After E. O. Essig; enlarged.)

copper, with distinct coppery spots on the elytra or wing cover.

Eggs. The eggs, which are somewhat circular, flattened and whitish, measure about 0.04 inch in diameter.

Larva. Mature larvae are whitish and measure about ¾ inch in length. They are flattened and have amber-colored heads. The region behind the head is broad and the body then tapers toward the posterior end.

Pupa. The pupa is flattened and typically beetle-like. At first it is creamy white, but by the time the beetle is ready to emerge it darkens.

SEASONAL LIFE HISTORY

The information on life history and habits of the Pacific flatheaded borer has been taken freely from the investigations reported upon by Burke (1929). In the lower elevations it has but a single generation a year. Transformation into the adult stage occurs from the first of April through July. Most of the beetles are found in June and July and it is during this period that most of the eggs are laid. The adults are sun-loving and quick in flight. The eggs are usually laid singly in cracks and crevices in the bark. In hatching, the larva bites out a hole in the bottom of the egg shell and mines directly into the bark. It works its way into the cambium, bark, or wood, and packs the waste and excrement in the mine behind. Until the larva is nearly full grown almost all the feeding and mining is done in the cambium. When full grown it bores into the outer wood and forms a slightly enlarged oval cell in which to pupate and transform into the adult. The entrance to the cell is plugged with borings from the wood. The mines constructed during the larval development wind about and sometimes girdle small branches or the trunks of

small trees in a spiral. Larval development is usually completed by early fall. The larva then enters the prepupal stage to pass the winter. As noted above, pupation occurs in the spring and early summer and the adults emerge in greatest numbers during June and July. To gain freedom, the adult mines its way out of the pupal chamber. It does this by eating its way through the plug at the entrance of the pupal cell and then through the bark covering it. The emergence hole is elongate-oval and just large enough to allow the beetle to emerge from the host. The emergence holes are very characteristic and serve to identify the pest responsible for the damage.

DESTRUCTIVENESS

Where trees lose vigor for any reason they are likely to be seriously damaged by the Pacific flatheaded borer. Young transplanted trees are particularly subject to attack because during their establishment there is a period in which their condition is somewhat weakened. Also, the severity of attack may be associated with the number of beetles present in an area. The pest occurs over an extensive area, but injury is apparently greater in mountain districts, probably because of the closeness of many native hosts. Injury results from the feeding of the larvae in the cambium. This results in dead spots, and in some cases limbs or even trunks of small trees may be girdled and killed.

Fig. 61. Dicerca horni Crotch adults beside an emergence hole on a walnut limb.

Fig. 62. The adult of the spotted tree borer. (After E. O. Essig.)

DICERCA HORNI CROTCH

Dicerca horni Crotch (fig. 61) is somewhat similar in habits to the Pacific flatheaded borer. It attacks many kinds of injured and dying wild and cultivated hosts.

It has been found to be a common species attacking injured and dying walnut trees in the walnut-producing section around Walnut Creek. Besides walnut *Dicerca horni* Crotch infests such trees as alder, buckeye, ceanothus, madrona, oak, cherry, peach, plum, and prune.

SPOTTED TREE BORER (Family Cerambycidae)

The spotted tree borer, *Synaphaeta guexi* (Lec.), attacks walnut, but injury is fairly well limited to trees that are not in a vigorous condition. Besides walnut it infests numerous other plants including forest, shade, and fruit trees.

The adult (fig. 62) is a large, robust beetle measuring about ¾ inch in length. It is gray, marked with black and orange.

At rest on the bark of its host it is difficult to detect because it blends so well with the background. Mature larvae are cylindrical, have amber heads, creamy white bodies, and measure more than an inch in length. They mine through the heartwood of the host and the exit hole through which the adults emerge is circular and measures about 3/8 inch in diameter. The adults are present during the late spring and early summer. The larvae breed in injured, dying, and dead trees. Trees in vigor are not attacked unless there is an injured area such as a broken limb.

NAUTICAL BORER (Family Cerambycidae)

The nautical borer, *Xylotrechus nauticus* (Mann.), attacks walnut but mainly breeds in damaged or recently killed wood.

Linsley and MacLeod (1942) observed the nautical borer attacking the black walnut rootstock of trees that appeared healthy, but which upon closer examination were found to be suffering from a disease.

The adults (fig. 63) measure 3/8 to 1/2 inch in length and are somewhat cylindrical in shape. They are grayish black, with three white markings on each of the wing covers. The larvae are creamy white, have amber-colored heads, and when mature measure up to 3/4 inch in length. Larval development occurs in the woody portions of the host. The burrows are circular and the holes through which the adults emerge are round and measure about 1/8 inch or a little more in diameter.

CALIFORNIA PRIONUS (Family Cerambycidae)

The California prionus, *Prionus californicus* Mots., is a native species which according to Essig (1926) probably normally breeds in dead and decaying roots and stumps of live and deciduous oaks. However, he stated that it readily attacks living and dead roots of alder, almond, cherry, cottonwood, peach, plum, poplar, prune, English and black walnut, and frequently kills both fruit trees and native trees. Morrill (1915) has reported it as attacking English walnut, and Crawford and Eyer (1928), and Eyer (1942) observed it as a serious pest of apple in New Mexico. Damage to walnuts is in feeding upon and mining the roots.

The adult is a large, smooth, shiny, uniformly dark reddish-brown beetle measuring about 2 inches in length. On either side of the prothorax there are three sharp projections. The adults are present during the summer; they are nocturnal and attracted to light. Larval development takes several years, and

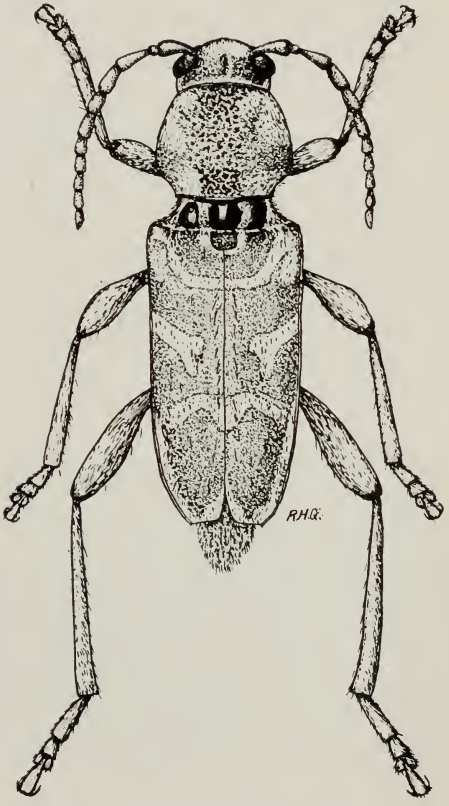


Fig. 63. An adult of the nautical borer. (After E. O. Essig.)

when mature the larvae become almost 3 inches long. They have dark-colored heads and a creamy white, strongly segmented body.

LEPTIDIELLA BREVIPENNIS (MULSANT) (Family Cerambycidae)

Leptidiella brevipennis (Mulsant) is a small cerambycid beetle, the larvae of which mine the twigs of walnut. The insect apparently prefers recently killed wood. It occurs throughout much of California and infests a number of hosts besides walnut. It is an introduced species and was first recorded from California in 1932 by Linsley (1933), who believed that it may have been introduced into this state on Persian walnut.

Other members of the family Cerambycidae that have been reported from or reared from English walnut in California as given by Barrett (1932) include *Hyperplatys californica* Csy., *Ipochus fasciatus* Lec., and *Ophistomis delicata* (Lec.). To these may be added *Phymatodes juglandis* Leng.

MONARTHRUM DENTIGER (LEC.) (Family Scolytidae)

Monarthrum dentiger (Lec.), an ambrosia beetle, has been reported by Linsley and MacLeod (1942) as attacking a large number of English walnut trees in Napa County. The adults confined their work to the black walnut rootstock where they entered the wood at a right angle to the surface, and at a depth of 2 or 3 inches where the galleries branched horizontally and ran through the sapwood. They reported that the entrance burrows were conspicuous because of accumulations of the boring frass. The attack by the beetles was limited to trees suffering from disease.

V FALSE CHINCH BUG

The false chinch bug, *Nysius ericae* (Schill), breeds in the grasslands and also in the weeds and covercrops in walnut orchards. The nymphs—or the immature form before wing development—are pale gray with reddish-brown abdomen. In May and June and again in September and October when the native grasses dry or are turned under, the nymphs migrate in countless numbers in search of green and growing plants. They are important only on young walnut trees. Boyce[7] reports they frequently kill the young twigs where they congregate and feed with their piercing and sucking mouth parts.

VI WALNUT HUSK FLY

This section is, for the most part, a condensation of certain portions of "The Bionomics of the Walnut Husk Fly," a more detailed study by Boyce (1934).

The walnut husk fly, *Rhagoletis completa* Cress., is known to have occurred in California since 1926. In October of that year near Chino in San Bernardino County, S. E. Flanders observed dipterous larvae feeding within the husk of several varieties of Persian walnut (Boyce, 1929). The first adult specimens were obtained in June, 1928, and erroneously determined as *Rhagoletis juglandis* Cresson. In 1929 *Rhagoletis completa* was described by Cresson (1929), who considered it a subspecies of *R. suavis*. Boyce, working with many more specimens of both *R. suavis* and *R. completa* than were available to Cresson at the time of his investigations, noted differences in the wing markings and the

[7] Boyce, A. M. (1935). Unpublished manuscript.

Fig. 64. The walnut husk fly, Rhagoletis completa, male showing wing markings, scutellum which is yellowish-white, and characteristic position of wings. (× 10).

Fig. 65. Right wing of Rhagoletis completa. The darkened pattern is characteristic of the species. (× 13)

male genitalia. On the basis of these findings, *R. completa* was considered a separate species.

The husk fly was probably an accidental introduction from New Mexico, Texas, Kansas, Nebraska, or Oklahoma, where it is apparently native. It has also been reported infesting walnuts in Oregon, Washington, Utah, and Idaho.

In California the husk fly is generally distributed throughout the walnut-producing areas of Ventura, Los Angeles, San Bernardino, Riverside, Orange, and San Diego counties. Localized infestations are present in Santa Barbara, Kern, Santa Clara, Stanislaus, Merced, Sonoma, and Napa counties.

Adult. The walnut husk fly (fig. 64), a rather colorful individual, is easily recognizable in the field. It is the only one of four related species attacking walnuts in the United States that is found in California. The general body color is tawny with yellow markings. From the lateral aspect, on a rather dark thorax there is a yellowish-white lateral stripe. The scutellum is also yellowish white and the abdomen marked with dark transverse bands on the dorsum. The eyes are turquoise blue. Preserved specimens lose much of their body color; however, the wing markings are the most important characters used in identification. The wings are hyaline with three nearly parallel transverse dark bands (fig. 65). The distal band continues along the costal margin or leading edge to the apex.

The female is slightly larger than the

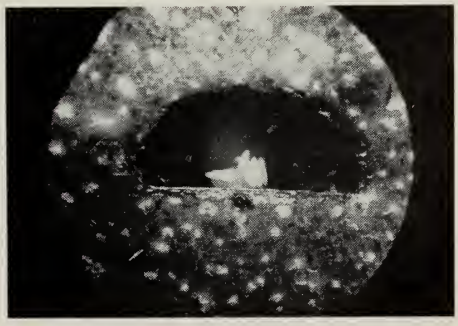


Fig. 66. Photomicrograph of walnut husk fly eggs in the husk tissue of walnut. (× 3½; after Boyce.)

Fig. 67. Infested hull tissue cut to show larvae in situ and the characteristic destruction of the husk with resultant stained shells. (After Boyce.)

male, the abdomen more pointed and equipped with an ovipositor.

The adult husk fly when at rest does not fold the wings over the back but keeps them in what might best be described as a "position of readiness," almost as though it were poised to take flight immediately.

Egg. It is elongate and curved (fig. 66). When first laid, it is pearly white but darkens as the embryo develops. The average length is $\frac{1}{25}$ inch and the width $\frac{1}{100}$ inch. The surface of the shell is covered with fine reticulations.

Larva. The newly hatched larvae, which are maggot-like, are almost transparent and the mouth hooks show up as darkened areas at the head end. The tracheal system is plainly visible and the larvae when ready to molt measure about $\frac{1}{16}$ inch in length. The second-instar larvae can be distinguished from the first-stage larvae by the presence of anterior spiracles. When individuals are ready to molt they measure slightly less than $\frac{3}{16}$ inch in length, the body is semiopaque, whitish, and the ingested food in the digestive tract is readily visible. The third- and last-stage larvae are typically maggot-like, plump, distinctly yellow in color, and with black mouth hooks. When ready to pupate they measure almost $\frac{3}{8}$ inch in length. (For taxonomic details of the larva, see Boyce, 1934.) Maggot-infested nuts appear in fig. 67.

Pupa. The straw-colored pupae resemble a grain of wheat (fig. 68). They are approximately $\frac{3}{16}$ inch in length by $\frac{1}{8}$ inch in width. The dark-brown anterior spiracles are evident. The lateral spiracles on the mesonotum and abdominal segments are also conspicuous.

SEASONAL HISTORY

Host resistance and accumulated soil-temperature conditions during dormancy apparently exert a profound effect upon the seasonal activity of *Rhagoletis completa* (Boyce, 1934). The walnut husk fly has but one generation per year (fig.

69). Adult emergence in southern California may begin the first week in July and continue until the latter part of September. Emergence has been observed both in the laboratory and the field in January and February during periods of relatively high temperatures. The total number of flies emerging during this host-free period appears to be very few and of no significance in reducing the potential infestation. Mating takes place approximately six to eight days after emergence, and the preoviposition period ranges from 10 to 20 days. When ready to lay her eggs the female tests the hull of the walnut with her ovipositor. Should the tissue be soft enough she will insert her ovipositor and with characteristic movements lacerate the hull tissue and deposit her eggs (fig. 70). About 12 or 15 eggs are deposited in each egg cavity. About 75 per cent of the egg cavities are made in the upper half or stem region of the walnut. All eggs are laid in healthy tissue. The period of maximum oviposition ranges from approximately August 25 to September 12.

In about five days the eggs hatch and the young larvae begin to feed, showing a marked preference for healthy tissue. Boyce (1934) recorded complete larval development in 36.8 days under field laboratory conditions and, under what he considered ideal field conditions, reported complete larval development in as few as 18 to 20 days.

The mature larvae appear to be gregarious, particularly where large areas of the husk tissue have been destroyed. If a means of exit from the hull is not available, mature larvae apparently are capable of making one by use of their oral hooks. Once an opening is made, the larva puts the anterior portion of its

Fig. 68. Top row: Walnut husk fly pupae showing comparative size to Bottom row: Grains of wheat.

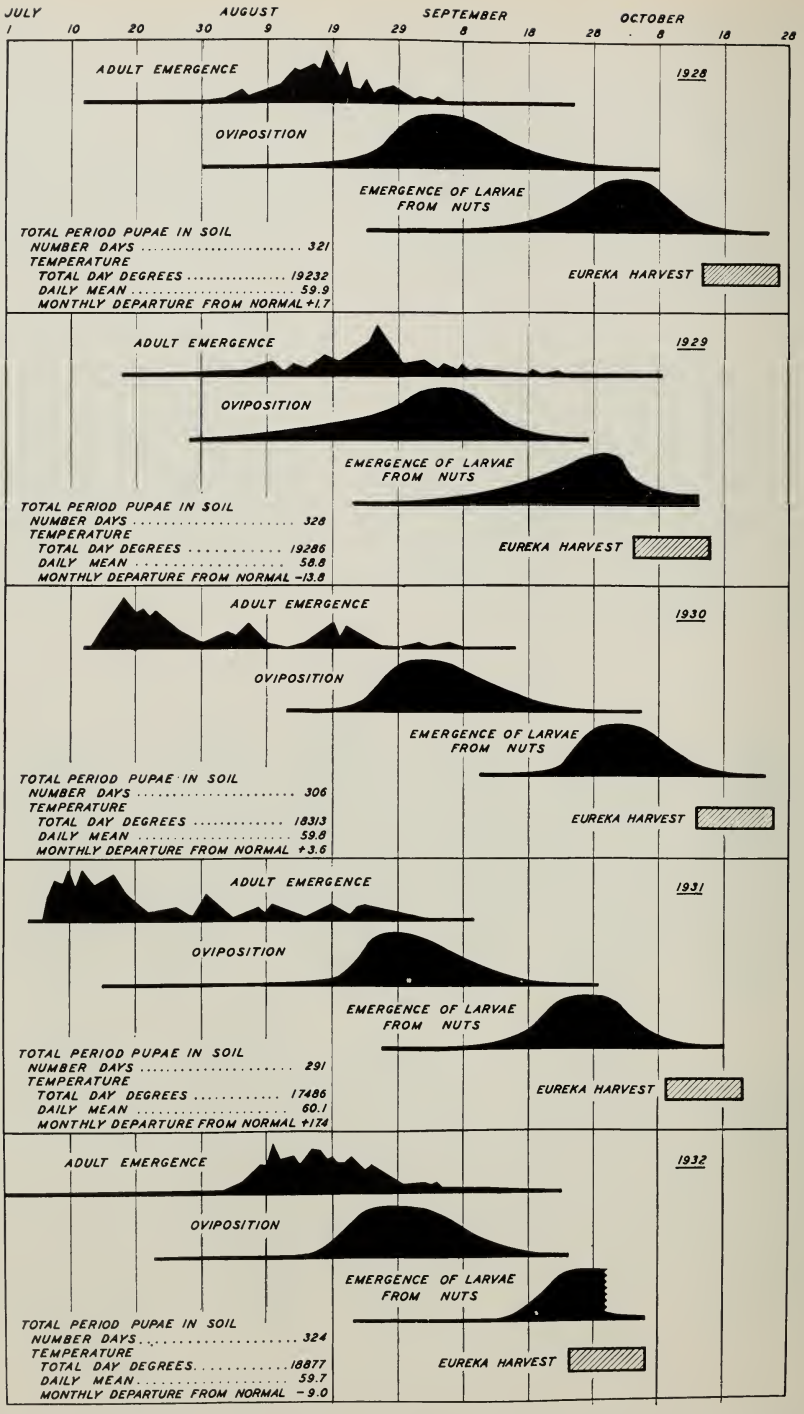


Fig. 69. Seasonal history of Rhagoletis completa in the Chino-Pomona area, 1928–1932. (After Boyce.)

body through the hole, which appears to be much too small, and moves the free portion of its body with a circular motion. This continues until the larva works its way out and drops to the ground. Larvae have never been observed making an exit through healthy tissue.

Upon contact with the soil the larvae immediately burrow downward, the soil type and moisture content determining the rate of penetration. Dry sandy types or packed soils are the most difficult to penetrate while loamy types under normal cultivation are easily penetrated. About 24 hours after entering the soil the puparium is fully developed. It is not absolutely necessary that the larvae enter soil to pupate. They have been observed pupating in sacks, on cement slabs, truck beds, in cracks in cement and wooden floors, and on the surface of packed soil. Under such conditions the mortality rate is very high.

All pupae formed during any one season do not emerge the following year. A small percentage may remain in the soil for as long as four years before emerging as adults.

DESTRUCTIVENESS

Besides English walnut, the walnut husk fly has but two hosts, black walnut and peach. Boyce (1934) listed two groups of cultivated walnuts according to the degree of their susceptibility to attack.

Very susceptible	*Slightly susceptible*
Eureka	Placentia
Franquette	Seedling (most types)
Mayette	Ehrhardt
Klondike	Ware
Payne	Neff
Seedling (certain types)	

In extensive studies he found that varietal resistance is apparently related to the hardness of the husk at the time of oviposition. As the walnut approaches maturity the hull softens, thereby enabling the female to insert her ovipositor into the husk tissue. The varieties most susceptible to attack are the thick hulled and the late maturing. However, it must be stated that all varieties of cultivated and native black walnuts within the infested area in southern California are subject to attack. On occasions the early-maturing, thin-hulled varieties are severely damaged. In 1950 heavy infestations were observed in the Chino area in Placentia and Ehrhardt varieties.

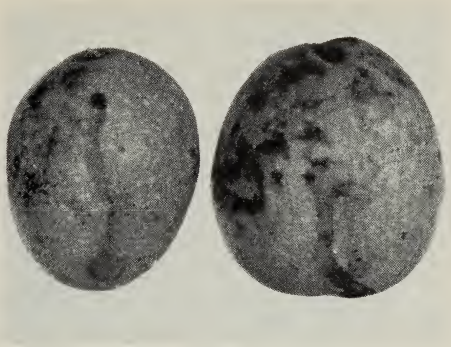


Fig. 70. Characteristic appearances of walnut recently stung by walnut husk fly. Note "tear stain" originating from lacerated tissue at site of oviposition.

The per cent of infested walnuts may vary greatly, the range being from less than one per cent to almost 100 per cent. The nuts on the north side of the tree are usually attacked first and sustain the greatest number of "stings." In addition, orchards which show good care and luxuriant growth are more prone to attack than those that are abandoned and water starved. Trees near leaking pipelines or at the end of an irrigation run where the soil is kept moist are usually more heavily infested.

The principal injury caused by the walnut husk fly is the staining of the shell (fig. 71). The destruction of the green husk tissue by larvae feeding within is easily seen on the hull surface. The feeding channels turn black from decay of the destroyed tissue and the blackened area enlarges as the larvae extend their feeding range. The blackened hull area may include the entire surface of the hull but generally it is approximately one half or less. Although

the husk tissue is destroyed, the outer epidermis is not attacked and maintains its normal shape and contour. The juices of the decaying husk stain the shell of the walnut. This stain cannot be removed by the normal bleaching process, nor is it economically feasible to use other methods. As a result, the nuts are classed as "culls."

Not all walnuts attacked by the walnut husk fly necessarily become culls. Seasonal conditions may be such that oviposition occurs rather late and the walnuts mature before larval development advances very far. The split hulls become dry and mealy and unfit as a food for the larvae. It is not unusual to observe 10 to 15 per cent of the crop on the tree infested, yet after harvesting and hulling only a minor loss is sustained.

The second type of injury is to the nut kernel. When the walnuts have been attacked relatively early in the season, the greater portion of hull may be subjected to mushy decay following the feeding activity of the husk fly larvae; this condition is accompanied by discoloration of the kernel and in some cases by mold and shriveling. The shrivel of the kernel may be related to the destruction of conductive tissue in the stem region of the walnut.

The husks of the majority of walnuts attacked by the husk fly do not split normally and allow the nut to drop. This condition increases the harvesting costs, as the nuts are not only more difficult to shake from the tree but after removal the husks must be hulled by hand or machinery. Some growers separate infested walnuts from uninfested to avoid staining of the latter.

CONTROL

Chemical Control

Recommendations for control of the walnut husk fly and other pests of walnuts are revised and published annually. These consist of two spray applications using malathion or parathion or bait sprays. The first spray is usually applied about the last week in July, the second three to four weeks later. The time for the first treatments and the interval between treatments vary from season to season and between localities, depending upon the emergence of the adult flies. The glycine and lye lure developed by Boyce and Bartlett (1941*a*) is used to determine the time for treatment.

Natural Control

The walnut husk fly has very few natural enemies, and of those existing none affects the population density to any appreciable extent. Boyce (1934) reported several species of pathogenic fungi causing mortality to adult flies in the laboratory. The mite, *Pediculoides ventricosus* New., and nymphs and adults of the anthocorid, *Triphleps insidiosus* (Say), were observed feeding on eggs of the husk fly. Several species of spiders and ants prey on the adults and larvae.

Some larval parasites have been introduced from Hawaii. *Opius humilus* Silv. and *Diachasma tryoni* Cam. were liberated in the field but no recoveries have been made (Clausen, 1956). In August, 1951, approximately 300 adults of *Opius formasanus* Fullaway[8] were released in a small grove in Pomona, California. About 45 per cent of the walnuts were infested with larvae of the walnut husk fly in all stages of development. The grove had not been subject to any pest control treatment for two years prior to the release nor were any treatments contemplated in the future. No recoveries were made.

Evidence of birds feeding on the larvae within the husk has been observed, particularly in late August and September. In some instances a considerable number of infested walnuts have been picked clean of larvae. Little evidence of bird activity has been seen later, just prior to harvest of the Eureka variety, even though the infestation approaches 100

[8] Obtained from Dr. S. E. Flanders.

per cent. It is assumed that the birds are a migratory species and their feeding on the larvae is for a limited period only.

Chickens are frequently seen around the hulling machinery at harvest time feeding on the larvae and scratching for pupae in the soil. Relatively few pupae are recovered from the soil in the vicinity of the hulling equipment where chickens are allowed to run.

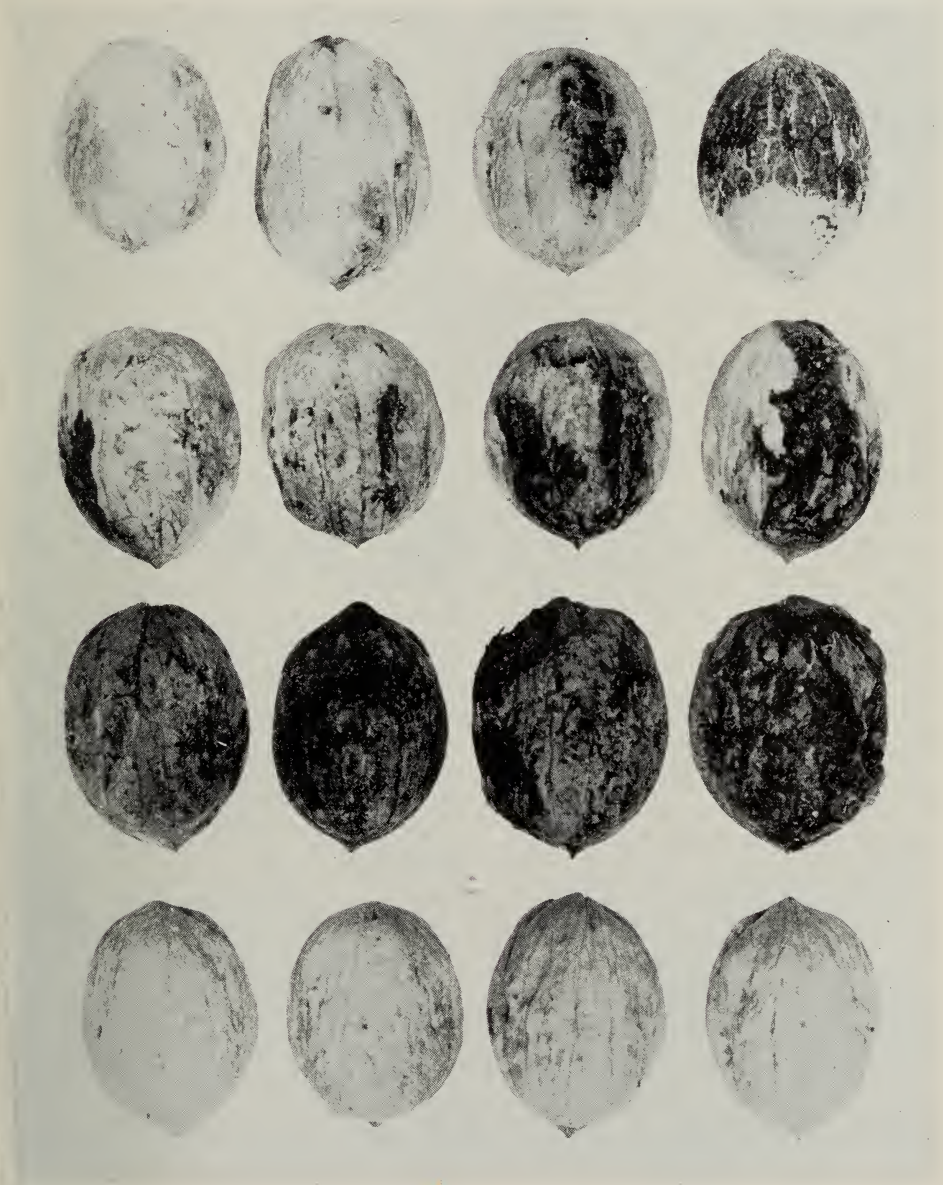


Fig. 71. Upper three rows: Varying amounts of shell surface staining by the husk fly. Lower row: Uninfested nuts. (After Boyce.)

VII SPIDER MITES

Spider mites rank among the more important pests attacking walnuts. They have long been known as a walnut pest. De Ong (1918) reported them as seriously attacking this crop, and Batchelor (1924) called attention to the fact that in some years spider mites do much damage in isolated instances. Smith (1939) noted spider mites as a pest of walnuts, and Batchelor *et al.* (1945) stated that spider mites are sporadic in occurrence but generally not a widespread pest of walnut.

The problem, however, increased with the advent of DDT. Michelbacher *et al.* (1946) and Michelbacher and Middlekauff (1949) observed increases in the spider mite population following applications of DDT to control the codling moth on walnuts.

The principal species involved are the European red spider mite, *Metatetranychus ulmi* (Koch.), the Pacific spider mite, *Tetranychus pacificus* McGregor, and the two-spotted mite, *T. telarius* (L.). Besides these true spider mites, walnut leaves are also attacked by the microscopic eriophyid walnut blister mite, *Aceria erineus* (Nalepa). In addition to this species, Michelbacher (1956*a*) has reported a false spider mite, *Brevipalpus lewisi* McGregor, attacking walnuts in the vicinity of Linden. The citrus red mite, *Metatetranychus citri* (McG.), which is a true spider mite, sometimes occurs on walnuts in southern California.

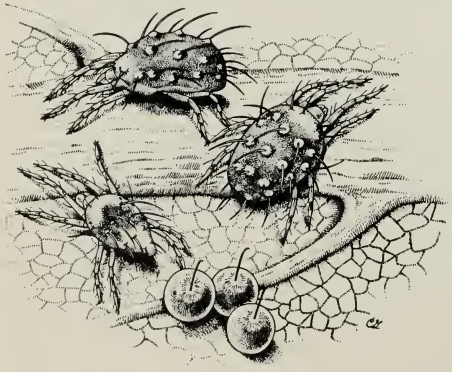


Fig. 72. European red spider mite on underside of walnut leaf. Upper: Adult females. Lower: Left, an adult male. Right, eggs. (× 30)

The descriptions given in this paper are only sufficient to aid in the field recognition of the species. Because of their small size, accurate determination of species often requires mounting and examining the specimens under magnification. For greater detail on species identification of the true spider mites, the work of Pritchard and Baker (1952) should be consulted.

The mites attacking walnuts pass through a number of generations each year. They are active during most of the growing season, and the period of most rapid development is during the warmest part of the summer.

EUROPEAN RED SPIDER MITE, *METATETRANYCHUS ULMI* (KOCH.)

Besides walnut this species of spider mite attacks a great many other hosts including almond, apple, cherry, pear, peach, plum, prune, berries, and some ornamental shrubs.

DESCRIPTION

The female of this species (fig. 72) measures about $\frac{1}{40}$ inch in length and has a globular brick-red body. On the dorsal surface there are four rows of long, strong, curved spines or setae which arise from whitish spots or tubercules. Females that have fed heavily sometimes appear greenish. The eggs are red, slightly flattened, and have on the upper surface a whitish stipe which is bent over at the tip. The species is found mostly on the upper surface of the leaves,

where it spins little or no webbing. As the population increases, more and more activity occurs on the under surface of the leaves.

SEASONAL LIFE HISTORY

The winter is passed in the egg stage on the twigs and limbs of its host. Under conditions of extreme infestation egg deposition may be heavy enough for the twigs to look as though they were covered with a red-brick dust. The eggs hatch in the spring and from then on to fall many generations are produced. Multiplication on walnuts does not become apparent until early summer. During the spring the rate of increase is rather slow, and large and destructive populations are usually not encountered until midsummer to early fall. Most activity and feeding at the start occur on the upper surface of the leaves. The females tend to lay their eggs along the ribs of the leaves; little if any webbing is produced. Because chlorophyll is destroyed by the mites' feeding, the leaves turn a bronzy green. Even seriously injured leaves tend to remain on the trees. With the approach of fall the adult females move to the twig growth to lay overwintering eggs (fig. 73). These eggs are laid over a rather prolonged period, and activity of the pest comes to a complete halt with the beginning of cold weather.

Fig. 73. Overwintering eggs of the European red spider mite on walnut twig. (Greatly enlarged.)

CITRUS RED MITE, *METATETRANYCHUS CITRI* (MC G.)

This mite is commonly found on walnuts in southern California where citrus plantings adjoin walnut groves. The walnut is apparently a poor host to the citrus red mite because when the mites appear in what could be considered fairly large numbers there is little evidence of feeding.

The citrus red mite is not so active in late May and June as the European red mite and, for the most part, remains quiescent in the depressions along the leaf midrib and veins.

PACIFIC SPIDER MITE, *TETRANYCHUS PACIFICUS* MC GREGOR

This species of spider mite severely attacks a number of cultivated and wild hosts besides walnut. Among these are almond, apple, cherry, plum, prune, pear, grape, and blackberry, as well as field and truck crops, such as cotton, alfalfa, corn, beans, and melons. Wild hosts include morning-glory, pigweed, and milkweed.

DESCRIPTION

Adult females (fig. 74) measure about $\frac{1}{40}$ inch in length. Active females are greenish or pale yellow, with a large, dark spot on each side near the middle and another pair of dark spots near the end of the body. Feeding usually occurs on the undersides of the leaves, where quantities of webbing are produced. The eggs are spherical and watery white. The bright-orange overwintering females are usually found under the bark or in other protected locations.

Fig. 74. The Pacific spider mite on underside of walnut leaf. Upper: Adult females. Lower: An adult male. Note eggs along the midrib. (× 30)

SEASONAL LIFE HISTORY

The Pacific spider mites usually overwinter as hibernating females, although Pritchard and Baker (1952) reported that in the San Joaquin Valley the mites appeared to continue reproduction on vetch during the winter of 1950–51. On walnuts, the hibernating females in the spring leave their overwintering quarters which, in the main, are protected locations under the bark of trees. Reproduction at first apparently is rather slow and large populations are usually not encountered until summer and early fall. Most feeding and other activity are confined to the lower leaf surface.

Quantities of webbing are produced; under conditions of serious attack the foliage may be festooned with it. The watery-white eggs are laid at random over the underside of the leaves and throughout the webbing. The areas of feeding become pale in color; and besides eggs and active forms of the mite, the attacked area may be covered with shed white skins of the pest. Seriously attacked foliage takes on a bronzy-brown appearance, dries up and falls from the trees. As leaf feeding continues, the foliage becomes less suitable for multiplication and the spider mite population declines. As a result, the largest populations are found at the margins of heavily infested areas or on attacked leaves just before injury causes their rapid decline. With the approach of fall, the overwintering bright-orange females are produced. The production of these individuals takes place over an extended period; under conditions of heavy infestation they can easily be seen working their way down to the trunks of the trees in search of places to overwinter under the bark or in other protected locations.

TWO-SPOTTED SPIDER MITE, *TETRANYCHUS TELARIUS* (L)

The two-spotted spider mite (fig. 75) has a very large host range. Besides walnuts it attacks many cultivated plants and weeds. Its cultivated hosts include many deciduous fruit trees, almond, flowering plants, ornamental shrubs and trees, small fruits, and truck and field crops.

DESCRIPTION

In size and habits the female of this species is much like that of the Pacific spider mite. The active females are globular, and vary from a yellowish to a greenish color. On each side of the middle of the body is a prominent dark spot. When the mites are feeding the spots may enlarge to the point where they cover most of each side of the body. The female of the two-spotted spider mite can be distinguished from that of the Pacific spider mite by its lack of dark spots found near the tip of the body in the latter species. Feeding usually occurs on the undersides of the leaves where a moderate amount of webbing is produced. The eggs are spherical, watery white, and lack a dorsal stipe. The overwintering females are dull orange in color. It is interesting to note that the females of all species of true spider mites discussed are larger and more robust than the

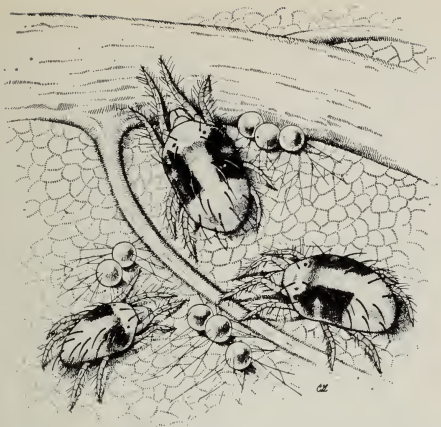


Fig. 75. The two-spotted spider mite on underside of walnut leaf. Large individuals are adult females; small specimen is adult male. Note scattering of eggs. (× 30)

males. Even the females are small, however, ranging in size from about $\frac{1}{40}$ to $\frac{1}{50}$ inch.

SEASONAL LIFE HISTORY

The activity of the two-spotted spider mite on walnut is much the same as that given for the Pacific spider mite. Somewhat less webbing is produced, and as fall aproaches there is a tendency for the overwintering dull-orange females to be produced. According to Pritchard and Baker (1952) the pest may continue activity throughout the year if suitable hosts are available. If hosts are not available, dull-orange overwintering females are produced. These spend the winter about the base of the plants or in any other protected location they can find. In the spring they leave their hibernating quarters and lay eggs on any available host. Multiplication is slow at first, but increases as the weather gets warmer, so that many generations are produced during the growing season.

Pritchard and Baker (1952) stated that the two-spotted spider mite ordinarily multiplies in deciduous fruit orchards during the spring on weeds and sucker growth and later, as summer advances, migrates to the trees. This situation also probably holds true on walnut.

TETRANYCHUS CINNABARINUS

Another species of *Tetranychus* that has been taken on walnut in Southern California is *T. cinnabarinus.*

WALNUT BLISTER MITE, *ACERIA ERINEA* (NALEPA)

The walnut blister mite is known to attack only walnut, although a rather closely related species infests black walnut. It is easily recognized by the characteristic injury it causes.

DESCRIPTION

This is a watery-colored, cylindrical-elongate posteriorly tapering microscopic eriophyid mite.

SEASONAL LIFE HISTORY

The walnut blister mite winters over in the dormant leaf buds. Its activity starts when the leaf buds begin to push in the spring. As soon as the leaves appear,

Fig. 76. Leaflets infested with the walnut blister mite. Left: Leaf shows injury as it appears on the under surface. Right: Leaf shows injury as it appears on upper surface.

tiny blister-like swellings can be detected, which grow in size as the leaf develops. The mites continue to multiply and develop within the infested area on the under surface of the leaflet. Their feeding results in the dense yellowish or brownish erineum on the lower surface of the leaflets and the blister-like swellings on the upper side (fig. 76). In the fall the mites find their way to the leaf buds that give rise to the next season's leaves.

FALSE SPIDER MITE, *BREVIPALPUS LEWISI* MC GREGOR

Besides walnut, this mite is known to attack such crops as citrus and pomegranate. Experience with the false spider mite on walnut is too limited to make any definite statements concerning its seasonal life history.

DESCRIPTION

This is a very small, flattened species that can barely be seen with the naked eye. The mites are somewhat orange in color with tiny black spots. They spin little or no webbing.

SEASONAL LIFE HISTORY

The false spider mite is known to pass the winter as an adult, settling about dormant leaf buds and in similar locations. Spring activity is apparently rather slow, and a considerable amount of time is necessary for the mite to increase in sufficient numbers to become noticeable. With the season's advance the pest can multiply to a point where infested leaves practically swarm with them. Where the population density is heavy, the infested leaves become coppery. Under conditions of severe infestation the mite causes defoliation, the dropped leaves coated with the mites shed white skins. Their damage is similar to that caused by the Pacific spider mite and the two-spotted spider mite; but the coppery color of the leaves, and the fact that little or no webbing is produced, serve to differentiate the work of this pest from that of the Pacific spider mite and the two-spotted spider mite. In late fall the false spider mite moves back to its winter quarters.

DESTRUCTIVENESS

Spider mites injure walnuts by sucking the cell juices. The feeding results in destruction of the chlorophyll; under conditions of severe attack, the leaves lose color, and in the later stages of infestation dry up and fall (fig. 77). High temperatures favor rapid development and multiplication and, as a consequence, most damage is done in the summer and early fall. Under conditions of severe infestations the vigor of the trees is reduced, and the premature loss of foliage exposes the developing walnut crop to sunburn. Further, the dropped leaves greatly interfere with harvesting operations.

Destructive populations usually first appear on the southeast side of the trees. The species of spider mite involved varies with locality and different seasons. In northern California the Pacific spider mite is the most important species, the European red spider mite the next in importance; while in southern California the European red spider mite and the two-spotted spider mite are of greatest concern.

Infestations in late season after the crop has matured apparently do not affect the quality of the nuts to any great extent. However, if there is a heavy drop of leaves, harvesting of the crop is more difficult. Where noticeable defoliation and heavy mite damage appear by or before the first of August, reduction in the quality of the crop can be expected. It is possible that serious infestations, especially if repeated the following year, may adversely affect subsequent crops. Where defoliation occurs early, the trees tend to send out new growth, a condition favoring winter killback if the winter is cold. Considerable experimental information has been obtained to show that

Fig. 77. Left: Trees show serious defoliation by spider mites. Right: These trees have escaped injury by a protective spray.

early and severe infestations can greatly reduce the quality of the developing crop. This is well illustrated by the results obtained in an experimental orchard at Modesto, where the quality of the nuts in a spider mite free treatment was compared with that obtained from a treatment that failed to control the pest. The information secured was as follows:

	Per cent sound nuts	*Per cent light-colored meats*	*Weight of meats per 100 nuts in ounces*
Mite-free treatment	96	55.0	20.9
Mite not controlled	86	10.3	16.6

The data clearly show to what extent spider mites reduced quality. They caused a marked reduction in soundness, color, and weight of meats.

A number of factors favor an increase in the spider mite population. Important among these are insecticides, dust, dryness, and the migration of spider mites from adjacent, heavily infested crops and weeds.

DDT and related insecticides tend to increase the spider mite problem. Further, it has been determined that as the dosage of DDT is increased, the danger of spider mites becoming a problem also increases. (Middlekauff and Michelbacher, 1950; Michelbacher and Bacon, 1952; Ortega, 1952.) Because of this, DDT should be used at the lowest possible concentration that will insure satisfactory control of the codling moth.

Why DDT should cause a rise in the spider mite population probably involves a complexity of factors so interwoven that at the present time it is not possible to obtain a clear understanding of all that happens. More than the destruction of natural enemies is concerned, as has been determined by investigations reported upon by Huffaker and Spitzer (1950) and Davis (1952). Insecticides other than DDT and its related group are sometimes responsible for induced increases in the spider mite population. In some cases the response probably involves physical or physiological factors or interference with natural control, or a combination of these. It is rather certain that any treatment which is ineffective against spider mites, but which is highly destructive to their natural enemies, is likely to result in an increase in the spider mite infestation.

Dust tends to induce an increase in the spider mite population. Serious and destructive infestations frequently develop along dusty roadways, or where dust drifts through an orchard from adjacent land being graded or otherwise worked. The dust deposited from frequent applications of insecticidal dusts used to control the walnut aphid can result in serious spider mite infestations (Michelbacher and Bacon, 1952). Large spider mite populations have occurred where frequent applications of nicotine dusts have been made for aphid control. However, there is no reason why insecticidal dusts should not be used so long as the treatment results in effective control so that frequent applications are not necessary.

Serious migration of spider mites to walnut sometimes takes place where orchards are adjacent to heavily infested crops or weeds. The trees in contact with these sources often suffer destructive defoliation.

Dryness also favors the development of damaging spider mite populations and frequently contributes to the problem.

Serious damage by the walnut blister mite seldom occurs. Although the pest is widespread it seldom reaches an economic level. In rare instances trees are severely infested, but at most this situation is usually confined to only a small portion of a tree.

CONTROL

As with other pests of walnuts, a certain level of spider mite infestation can be tolerated. Serious damage to the crop is not likely to occur until feeding has reached a stage where it can be noticed on close observation. Control measures, however, should be applied before serious defoliation.

Spider mites are controlled or held in check either by natural factors or by artificial measures.

Natural Control

The important factors that constitute natural control are physical and biological. The physical factors are those concerning weather and climate. These may be favorable or unfavorable to the pest. For example, hot dry periods tend to stimulate a rapid increase in the population while damp cool weather has the reverse effect.

The biological factors, which principally include predators, are extremely important in regulating spider mite pop-

Fig. 78. Stethorus picipes Casey. An important predator of spider mites on a walnut leaf. Left: A pupa. Center: A full-grown larva. Right: Small black adult.

ulations. Often they suppress population to a subeconomic level. It is not uncommon to see the spider mite population begin to increase, only to have it reduced by natural enemies to noninjurious numbers before any serious damage is done. In some cases the spider mite population may be so thoroughly eliminated that the pest is difficult to find. Among the more important predators are the ladybird beetle, *Stethorus picipes* Casey (fig. 78), anthocorid bugs, the green lacewing, predacious laelaptid mites, and on occasions the six-spotted predacious thrips, *Scolothrips sexmaculatus* Perg.

If it were not for the beneficial action of these natural enemies, the control of spider mites would be a much more difficult problem than it now is. Everything possible should be done to protect them. Excessive treatment for other walnut pests should be avoided, and treatments that are necessary should be so thoroughly and carefully applied that frequent application will not be needed.

Artificial Measures

A number of artificial measures are useful in suppressing spider mites. These fall under the headings of cultural and chemical control. Among beneficial cultural measures are destroying weeds, keeping orchards in vigorous growing condition, and avoiding practices that stir up dust. Further, orchards should never be allowed to suffer for lack of moisture, because dryness, especially during hot spells, favors injury by spider mites. Also, where possible, avoid planting crops that are subject to serious attack by spider mites next to walnuts. Dusty lanes or roads should be oiled or paved wherever possible. Under all conditions avoid fast or unnecessary driving on dusty lanes or roads.

Where it is apparent that natural factors, or cultural practices, will not check the spider mite population, chemical measures should be used. Acaricides should be applied before a serious infestation or defoliation has taken place. A number of promising materials are available, in such acaricides as Systox, ovotran, Kelthane, and aramite. Satisfactory results with these materials are dependent upon proper dosage thoroughly applied with efficient equipment. Except where spider mites are resistant to parathion, repeated, thorough applications will tend to suppress the population. Other new materials are being developed which also show a great deal of promise, and it appears that a number of these will eventually find their way into the walnut pest-control program. Needless applications for the control of spider mites should be avoided, because they tend to select strains resistant to acaricides. Therefore, the danger of this occurring increases with excessive use.

VIII SCAVENGER SPECIES

Many species of insects have been found inhabiting walnut husk tissue injured by blight, by the walnut husk fly, or by mechanical means. The most frequently seen are larvae of the scavenger flies, *Euxesta putricola* Cole, and *Lonchaea occidentalis* Mall., Boyce (1934). Growers sometimes confuse these larvae with the larvae of the walnut husk fly.

The fire ant, *Solenopsis germinata* (Fab.); and the dried-fruit beetle, *Carpophilus hemipterus* (Linn.), are frequently found feeding on the kernels of the fallen nuts. Entry to the kernel is made in the soft pithy tissue of the stem end or through a codling moth injury.

IX INSECTS ATTACKING WALNUTS IN STORAGE

A number of insects that attack stored products may seriously infest walnuts in storage. The most important among these are the Indian-meal moth, *Plodia interpunctella* (Hbn.), the Mediterranean flour moth, *Ephestia kühniella* Zell., and the saw-toothed grain beetle, *Oryzaephilus surinamensis* (Linn.). All of these insects feed on many types of stored foods and are widely distributed both in nature and in the abodes and storehouses of man. They are ever present and man must be constantly on the alert to prevent their gaining entry to stored nuts or, if infestations have become established, to destroy them before they have had an opportunity to become destructive.

INDIAN-MEAL MOTH

DESCRIPTION

Adult. The adult of the Indian-meal moth, *Plodia interpunctella* (Hbn.) (fig. 79A) is unusually distinctive. It has a wing spread of about $\frac{5}{8}$ inch; the outer two thirds of the forewings are coppery brown, while the basal third is pale gray. The hind wings lack distinctive markings and are more or less uniformly gray.

Egg. The egg is small and white when first laid but darkens as the embryo develops (see fig. 79B).

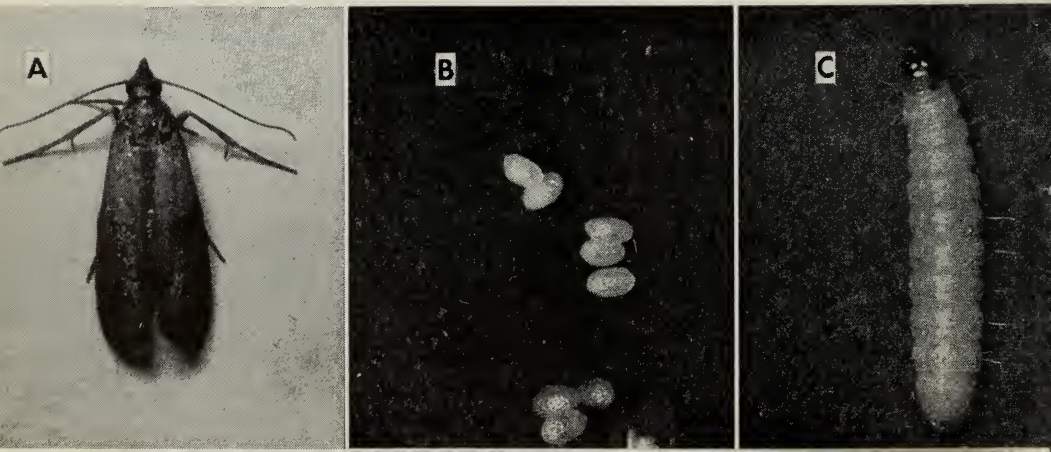
Larva or Caterpillar. The larva, shown in figure 79C, which hatches from the egg is about $\frac{1}{2}$ inch long when full grown and is tan colored with a faint yellowish or greenish tinge. The head and prothoracic shield are dark brown. The body is sparsely covered with rather long hairs, but there are no dark spots about the base of the hairs as found in the case of the larva of the Mediterranean flour moth (see fig. 80C).

Pupa. The pupa (fig. 79E), which is light brown, is found in the silken cocoon spun by the larva (fig. 79D). Fragments of frass and food are generally incorporated into the cocoon.

SEASONAL LIFE HISTORY

The adult moths lay their eggs on or near material that may serve as food for the larvae. Under favorable conditions only four or five weeks are necessary for the insect to complete its development from egg to adult. Like other stored-food pests, development is largely governed by temperature. Under favorable conditions there may be as many as seven or eight generations in a year. Development is most rapid during the summer. In the cooler periods of the year it is slow, and out-of-doors or in unheated buildings Simmons *et al.* (1931) have shown that five to seven months are necessary for the insect to complete a generation. Al-

Fig. 79. The Indian-meal moth, Plodia interpunctella (Hbn.): (A) Adult; (B) Eggs; (C) Larva; (D) Cocoon; and (E) Cocoon opened to show pupa. (× 3¼)



though the larvae eat their way through foodstuffs, they usually come to the outside to spin their cocoons and pupate. Webbing is always associated with infestations by this insect. Under conditions of severe infestations larvae frequently wander away from the infested material and may be found far removed from the material in which they develop.

Besides nuts, the Indian-meal moth is one of the most important pests of cereal and cereal products, dried fruit, chocolate candies, and various other confections.

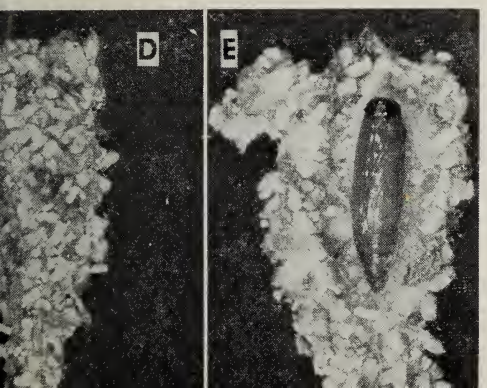
MEDITERRANEAN FLOUR MOTH

DESCRIPTION

Adult. The adult of the Mediterranean flour moth, *Anagasta kühniella* Zell. (see figure 80A), has a wing spread of about ¾ inch. The forewings are lead gray, speckled with black, or may have transverse wavy black lines. The hind wings are a more or less uniform lighter gray color.

Egg. Eggs (fig. 80B) are laid on or near any product that is subject to infestation.

Larva or Caterpillar. The larva (see figure 80C) when mature measures about ½ inch in length. It is whitish or slightly pinkish and the prothoracic shield and head are brown. The body is sparsely covered with rather long hairs, some of which, particularly those in the subdorsal row, have black spots about the base, a character distinguishing this species from the Indian-meal moth. The pupa is light brown (fig. 80E), and is enclosed in a silken cocoon (fig. 80D).



SEASONAL LIFE HISTORY

Development is largely regulated by temperature and, where conditions are favorable, the insect may have four or five generations in a year. The larvae spin quantities of webbing and feed throughout the infested produce. Upon completing their development the larvae crawl to the outside and construct silken cocoons in which they pupate. These are most often found on or near the infested material.

The Mediterranean flour moth is world-wide in distribution and besides infesting nuts seriously infests cereal and cereal products, dried fruit, candies, and other confections.

SAW-TOOTHED GRAIN BEETLE

DESCRIPTION

Adult. The adult of the saw-toothed grain beetle, *Oryzaephilus surinamensis* (Linn.) (fig. 81A), measures about ⅛ inch in length. It is slender, flattened, hard-shelled, and brown. Under slight magnification the last two segments of the antennae appear slightly enlarged and the pronotum has a row of saw-like teeth along the sides and a long shallow depression on each side of the middle.

Egg. The eggs are laid in cracks and crevices of foodstuffs, where they are usually deposited in groups, and require from three to 17 days to hatch. Each female may lay several eggs a day and in a lifetime, which ranges from two months to more than three years, lays upward to 300 eggs.

Larva or Caterpillar. The larva (fig. 81D) is slender, pale colored, with a brownish head. Frequently it has pale-brownish bands on the body segments. The posterior end of the body is pointed. The mature larva hardly measures ⅛

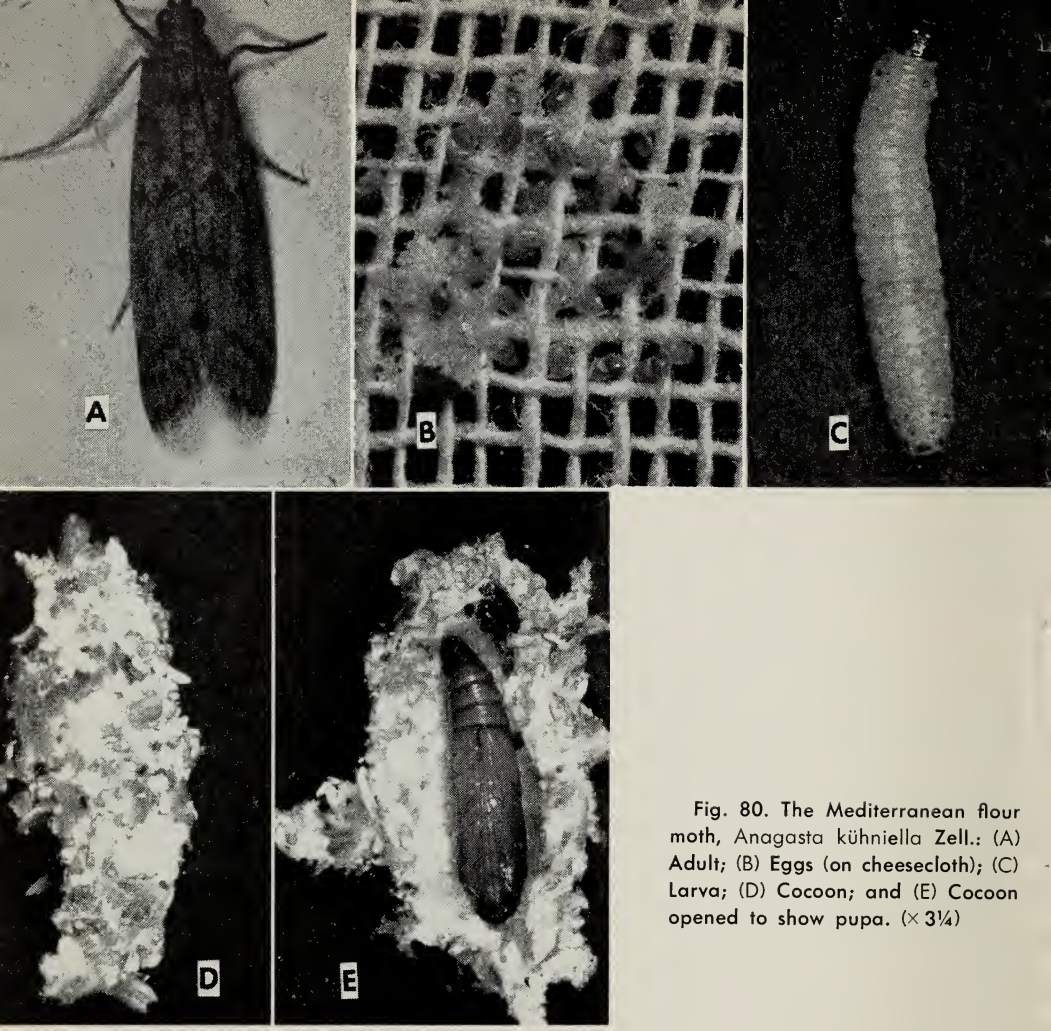


Fig. 80. The Mediterranean flour moth, Anagasta kühniella Zell.: (A) Adult; (B) Eggs (on cheesecloth); (C) Larva; (D) Cocoon; and (E) Cocoon opened to show pupa. (× 3¼)

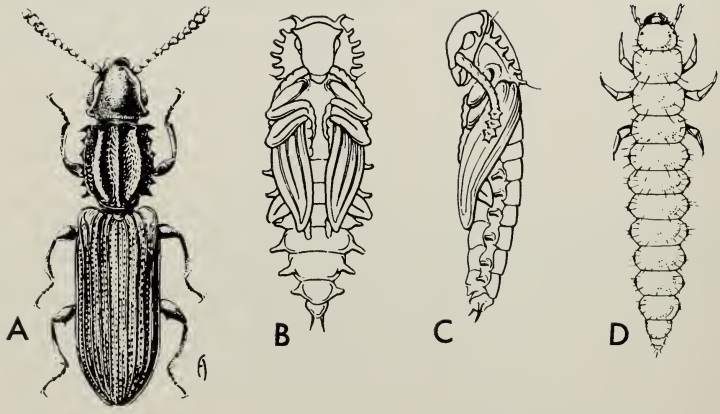


Fig. 81. The saw-toothed grain beetle, Oryzaephilus surinamensis (Linn.): (A) Adult; (B) Pupa, ventral view; (C) Pupa, lateral view; (D) Larva. (All × 15) (After Linsley and Michelbacher, 1943.)

inch in length and is likely to escape detection unless a careful search is made. Upon completing development the larva pupates. The pupa (fig. 81B and C) at first is pale, but darkens with transformation to the adult stage. The head is turned under, the legs pulled up tight, and the wing covers are coiled around the body. Along each side of the body there is a row of spine-like structures.

The adult beetles rarely if ever fly but may be seen crawling over infested food material. The larval stage lasts from two to eight weeks, depending upon the season. The adults tend to migrate and are sometimes found rather far removed from the products in which they developed.

SEASONAL LIFE HISTORY

The saw-toothed grain beetle is one of the commonest and most important of the pests attacking stored products. Its facility for rapid reproduction, long life of the adult, its ability to migrate, and its secretive habits are some of the factors that make the insect a troublesome pest. It is especially destructive to nuts, dried fruit, and cereal products.

CONTROL

The control of stored product insects attacking walnuts in storage is greatly aided by following the best of sanitary measures. Also every effort should be made to avoid introducing them into storage areas in infested products or in infested containers.

Nuts can be protected by placing them in cold storage. Where general infestations occur and cold storage is not available, fumigation must be resorted to.

Where there is no danger of contaminating the nuts, a residual type of spray in conjunction with sanitation practices will help in the control of the pests.

ACKNOWLEDGMENTS

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